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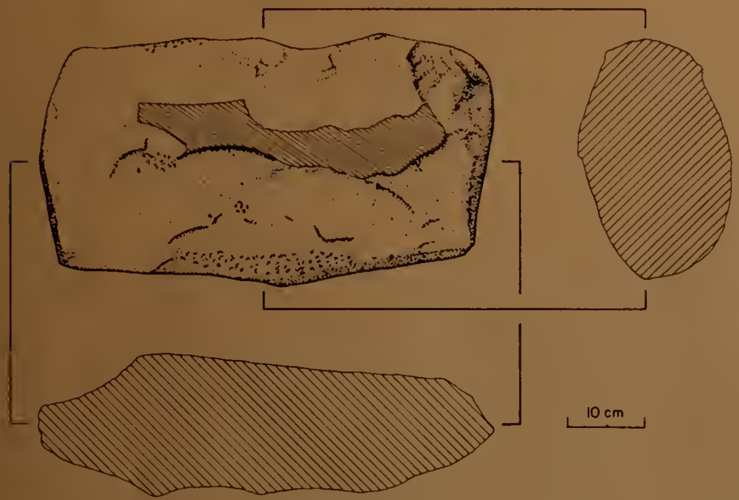

A Ground Stone Implement Quarry on the Lower Colorado River, Northwestern Arizona

Bruce B. Huckell

CULTURAL RESOURCE SERIES No. 3

1986

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Bureau of Land Management
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Post Office Box 16365
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A Ground Stone Implement Quarry on the Lower Colorado River, Northwestern Arizona

by

Bruce B. Huckell

Cultural Resource Management Division
Arizona State Museum
University of Arizona

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ABSTRACT

Results of an archaeological and ethnological study of a very large ground stone tool quarry on the lower Colorado River near Bullhead City, Arizona, are presented. The general size and content of the quarry area as understood from survey is described, and the nature of the andesite being selected for tool manufacture is presented. The results of archaeological investigation of 10 discrete production loci is reported, and the kinds of artifacts from them are described. These include broken or aborted preforms, hammerstones, debitage, bracing rocks, and punches. Using results of detailed analysis of these artifacts and data from replicative experiments, a general or idealized reduction strategy for the manufacture of metates is presented. Ethnological and archaeological information are used to suggest that the quarry was utilized by the Mohave Indians, and perhaps their immediate Patayan ancestors. The sociocultural implications of such a technologically sophisticated mode of ground stone tool production are considered. It is suggested that a complex system of ground stone tool production, exchange, and utilization formerly existed among the Mohave, and through the use of comparative ethnological data it is shown that such a system is nearly unique in the Southwest and nearby portions of California and the Great Basin. Using data from a study of metate production in Oaxaca, the form that this system may have taken is presented. The implications of this system for the length of time the quarry was used are explored, and it is shown that the entire production of the quarry could be accounted for in a few hundred years. The presence of a second quarry for ground stone tools near Needles is also documented, and its implications for the use of the andesite quarry are considered. Finally, recommendations are made for future studies at both quarries.

A GROUND STONE IMPLEMENT QUARRY ON THE LOWER COLORADO RIVER, NORTHWESTERN ARIZONA

Bruce B. Huckell

Few parts of the desert Southwest present such a sterile, forbidding appearance as the mountains and bajada slopes that flank the Colorado River in the Mohave Valley of the Arizona, California, and Nevada tristate area. The relationship between the river and the surrounding bajada slopes is a study in contrasts, or of things in opposition. The river boasts water in abundance, and offers sustenance to plants, animals, and people along its banks. Until recently there were abundant mesquite, cottonwood, and willow trees there, offering food, shelter, and materials. Annual flooding renewed and enriched the soil of the sloughs and floodplain, permitting in good years abundant agricultural produce, the mainstay of the residents of this valley, the Mohave Indians. However, a short walk east from this green ribbon, up a steep terrace slope, brings one onto the Black Mountains bajada surface. The bajada sees less rain in an average year than does almost any other place in Arizona, as is evidenced by the scattered, scraggly creosotebushes, stunted cacti, and brown stems of sun-dried annuals and grasses. Dark brown to black boulders and gravel pavements coated with lustrous desert varnish reinforce the impression of barreness, and a mid-summer's afternoon visit to this bajada would convince all but the most ardent that the place had nothing to offer human beings.

However, recent opportunities to examine the bajada of the Black Mountains bordering the Colorado River on its east bank show that in fact these slopes contain a valuable commodity: andesite boulders of suitable quality for the manufacture of ground stone milling equipment. That this area had served as a quarry for ground stone tool material was first recognized several years ago by BLM Yuma District archaeologist Boma Johnson. In the course of archaeological survey work on BLM lands just east and southeast of Bullhead City, he and others (BLM 1984) encountered numerous, discrete concentrations of large, sharp-edged tabular pieces of rock. These were rather distinctive on a surface otherwise covered with rounded and subrounded rocks, and closer inspection of these tabular pieces revealed what appeared to be percussion features such as striking platforms, points of impact, bulbs of percussion, and previous flake removal scars on the exterior surfaces. However, these apparent "flakes" were quite large, some measuring up to 50 cm in maximum dimension. After some head scratching, it was decided to christen them "macroflakes." Continued examination of the spatially discrete loci showed that some had associated with them broken or abandoned "cores," in the form of large, subrectangular blocks or, occasionally, narrow, elongated cylinders. Also present at many loci were quartzite river cobbles with obvious battering on their ends; these do not occur naturally on the bajada. It was inferred that these loci were probably places where ground stone metates, pestles, and perhaps other tools had been manufactured prehistorically. Further, it

was found that the loci were extremely abundant, scattered across as much 25,000 acres of the Black Mountains bajada surface; in some areas several hundred separate loci per 640 acre section were documented.

In 1984 a decision was made by the BLM to dispose of 5.75 sections of land in the heart of the known area where these "macroflake" loci occur. The Cultural Resource Management Division of the Arizona State Museum was awarded a contract to perform a data recovery operation at a series of these loci within the proposed disposal parcels. Working closely with BLM Yuma District Archaeologist Boma Johnson and BLM State Archaeologist Gary Stumpf, a research plan was prepared by the author, and fieldwork at the loci was accomplished between April 29 and May 6, 1985. This work was done by Robert Neily and Ronald Beckwith of the museum with help from Don Simonis and Boma Johnson of the BLM. Data analysis was undertaken by the author in Tucson. Additional time was spent by the author at Needles in June and December to view a private collection containing finished ground stone tools from the Mohave Valley area and to talk with Mohave Indian informants.

Research Objectives and Methods

Three major research problem domains were defined for the investigation of the "macroflake" loci: (1) the regional cultural and temporal context within which the flaking of the boulders had been done; (2) the manufacturing technology that had been used to flake the boulders; and (3) the distribution and numbers of loci within the study area. Each problem domain was further defined by a series of specific questions. Within the first problem domain, data were sought concerning the types of ground stone tools being manufactured, the age and cultural affinity of the loci, and whether the implements were being manufactured for local use, trade, or both. Insofar as the second problem domain, manufacturing technology, was defined, information was needed to address questions on raw material selection, reduction strategies, and technical aspects of the flaking process. Finally, under the third problem domain, data were gathered concerning the size of the quarry area and the distribution of loci within it, geological data on the nature of the raw material, and whether certain parts of the quarry area had seen differential use for the manufacture of different types of implements.

The bulk of the research was archaeological in nature, consisting of the investigation and recording of loci in the quarry. A limited amount of experimentation was also done to attempt to better reconstruct the manufacturing process. In addition to the archaeological field work, time was also devoted to a search for finished ground stone tools that might have come from this quarry. This entailed visits to the San Bernardino County Museum, the private museum of Mac and Maggie McShan in Needles, the Colorado River Indian Tribes Museum in Parker, and letters to several other institutions. Visits with Mohave Indian informants were also made, and a thorough study was done of ethnographic sources on the Mohaves, other Colorado River Yumans, and neighboring tribes in Arizona, California, and Nevada.

A total of 944 "macroflake" loci was recorded in the 24 section area initially surveyed by BLM archaeologists, although only an average of 15.1 percent of each section was surveyed. Individual sections received covereage varying from a high of 48 percent to a low of 3 percent. Surveyors located 505 loci in the 5.75 sections of land that were finally selected for disposal. Figure 1 presents a map of the quarry area, showing its relationship to the river and Bullhead City, and the relative numbers of loci as determined by survey. As may be seen, the quarry covers an area at least 11.2 km by 8.0 km in size, with an apparent concentration of loci in Sections 20, 28, 30, and 32 of T20N R21E, and a second less dense concentration in Sections 4 and 6 of T19N R21E and Section 12 of T19N, R22W. A sole exception to this pattern is found in an isolated high density area in Section 12 of T20N R23W, where there are 210 recorded loci. These are reported to be due to a "small island of smaller basalt (sic) boulders which were very heavily used due to proximity to the river . . ." (BLM 1984, Appendix C, footnote 1). This locus will not be treated further, for it is isolated from the main quarry area, has not been studied in detail, and thus the kinds of products being manufactured here are not known. Most of the material in the main quarry area occurs on the bajada slopes above the 800 foot (185 m) contour, where entrenched streams and their many tributaries have cut deeply into the bajada, exposing the desired material. Of course, inventory of the private lands, which form a checkerboard pattern with BLM holdings in this area, might act to modify this apparent distributional pattern.

Due to the large number and highly redundant nature of the loci in the main quarry, as well as time and budget constraints, a sample of 10 loci was chosen for investigation. This represents 1.9 percent of the known loci in the area selected for disposal. These loci, chosen in consultation with BLM archaeologist Boma Johnson, were not selected at random but were chosen because of their integrity, size, ability to yield high quality information, and their location within the overall suite of parcels to be disposed. An eleventh locality, already collected by Johnson and housed at the Fort Mohave Indian Tribe headquarters in Needles, was also incorporated into the study.

Each of the 10 loci was examined using a standardized set of investigative procedures. First, the locus was photographed to document its appearance and condition. Next, the locus was covered by a 1 m by 1 m grid system; each archaeological specimen at the locus was then mapped and drawn in place, and received its own field number. Because of the sizes and quantities of artifacts, it was decided not to collect all the loci, but rather to record in the field as much pertinent data as possible. Two loci, one representing the manufacture of a metate and the other a pestle, were chosen for collection in their entireties. These loci were chosen because each contained not only debitage but also an aborted or broken preform and, in one case, hammerstones. At those loci not chosen for collection, a simple series of metric and nonmetric observations was made in the field. For debitage, these observations included: (1) condition (complete or fragmentary); (2) length, width, and thickness (length being the distance from the point of hammerstone impact to the point of last detachment, width being perpendicular to

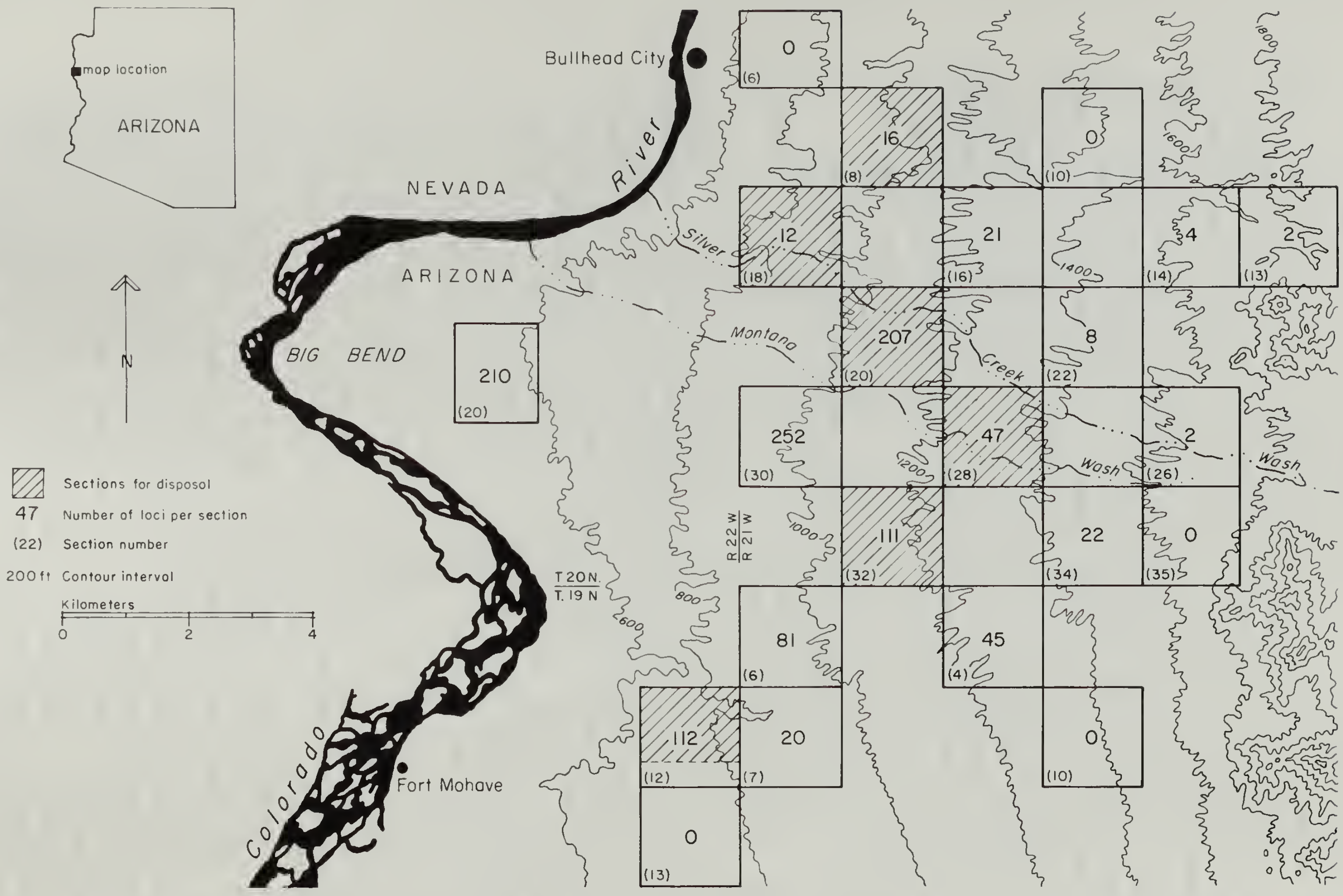

Figure 1. The Big Bend Quarry area, showing its extent and density of production loci as known from survey.

and at the midpoint of the length, and thickness being measured at the intersection of the length and width dimensions; maximum dimension was used for fragmentary debitage); (3) striking platform type (cortical, plain, dihedral, or faceted); (4) amount of exterior surface cortex (75-100%, 50-74%, 25-49%, or 0-24%); and (5) the number of previous flake scars over 5 cm in maximum dimension on the exterior surface. For preforms, or "cores," maximum length, width, and thickness were recorded, and the preform was photographed and sketched. Hammerstones were identified as to material type; their maximum length, width, and thickness were recorded; and they were photographed or sketched. The two loci that were collected received the same treatment, except that the analysis and recording of the debitage, preforms, and hammerstones was done out of the field. The same procedure was used to record the single locus that had been collected by Boma Johnson.

In the following sections these production loci are briefly described, and the nature of the debitage, preforms, hammerstoes, and other objects associated with them is presented.

The Production Loci

As noted above, the "macroflake" or production loci tend to occur as discrete concentrations of debitage, hammerstones, and aborted or broken preforms scattered across the Black Mountains bajada south and east of Bullhead City (Fig. 1), Arizona. It will be referred to as the Big Bend Quarry, named for a prominent bend in the Colorado River immediately to the west of it. The known quarry area, designated AZ F:14:123 in the site survey system of the Arizona State Museum, covers an area estimated to be in excess of 89.6 square km (30 square miles), and it is probable that it could be extended to the east and perhaps the north by additional survey. Most of the loci are located on the desert pavement surface of the bajada, but they may also occur on the slopes of the numerous small and large drainages that have dissected it. It is not unlikely that some loci occurred in the bottoms of the drainages as well, but these would have been dispersed by and lost to the occasional flooding of the channels over the years. In most cases a single locus appears to represent the reduction of a single boulder or cobble, although in a small number of cases multiple boulders may have been reduced in one location. For the most part, the distribution and relatively low (estimated to be less than 10%) frequency of the particular grade or quality of andesite being sought by the artisans ensured that the production loci would be scattered and discrete. This is not meant to imply that the loci are rare, for as Figure 1 shows as many as 252 loci may occur in about half of a single 640 acre section. The density figures presented for the surveyed sections on Figure 1 suggest that the loci are most abundant in that part of the quarry area south of Silver Creek Wash and including Montana Wash, with a second area of relatively high density along the Beale Wagon Road southwest of the first area.

Survey work has suggested that metates were overwhelmingly the most frequently produced ground stone implement at the Big Bend Quarry. Some pestles were also manufactured here, and it is also possible that mortars were occasionally made. One finished mortar, owned by the McShans of Needles, appears to be made of the Big Bend Quarry andesite. Mullers or manos were almost certainly made here as well, although there is at present very little direct evidence for their manufacture in the quarry area itself. However, it is possible that these could have been made at the detached "island" of smaller andesite cobbles west of the main quarry, or that such small tools were made away from the quarry area at habitation sites.

The material consistently sought by the artisans consists of a very finely vesicular, almost microvesicular, grade of andesite. In color it ranges from a dark grayish black to a purplish brown, looking very much like a basalt. Mineralogical tests (X-ray fluorescence) confirm that it is an andesite, however, containing 55 to 56 percent silica or more. The bajada contains igneous rocks that vary from nonvesicular to very coarsely vesicular, so the artisans chose only a very limited part of this rather great range of material textural variability.

Eight of the 10 loci investigated represent metate manufacture, including apparently successful efforts (Loci 1, 2, 3c, 10a, and 10c), and unsuccessful efforts (Loci 5b, 6, 7, 9, 10b, and 11). Success is defined here in the only terms possible: the presence of a preform at a given locus is taken to represent failure. Figure 2 presents photographs of two of the metate manufacturing loci which were investigated; their appearance is quite typical. The two remaining loci (4a and 8) represent unsuccessful pestle manufacture.

Table 1 summarizes the artifacts recorded at each locus. A few remarks in explanation of the artifact categories shown in the table are in order. Metate, pestle, and muller "preforms" refer to those artifacts that were in the process of being flaked at the loci. They seem to have been abandoned either when they broke or when an insurmountable technical problem in reduction arose. Debitage includes all the flakes from a single identifiable andesite boulder or cobble at a locus; "flakes of different material" include spalls accidentally or intentionally removed from hammerstones. Hammerstones are cobbles of local igneous rock and nonlocal quartzite with evident battering on their ends or edges. Finally, "bracing rocks" refer to local igneous cobbles with obviously fresh abrasion or scratching on their desert varnished surfaces. Each of these classes of artifacts is described in the following paragraphs. The information is derived from the loci investigated by the Arizona State Museum, augmented by information gathered by BLM archaeologists Boma Johnson, Duane Christianson, and Don Simonis during their surveys of the quarry area.

Figure 2. Photographs of production loci at the Big Bend Quarry. From upper left to lower right, Locus 4, Locus 7, Locus 9, and Locus 10.

Table 1

ARTIFACTS RECORDED AT THE INVESTIGATED LOCI

Locus	Metate Preform	Pestle Preform	Muller(?) Preform	Debitage	Hammer-stones	Bracing Rocks	Flakes of Different Material
1				102	7*		1
2				160			1
3c				88	2		
4a		1		41	3		
5a			1	128	7	3	1
5b	1			16	2	1	
6	1			47			
7	1			245	2		3
8		1		34			1
9	2			44	2	1	1
10a				128		1	
10b	2			15			
10c				58	3	1	
11	1			105	6		1
Total	8	2	1	1,211	34	7	9

* These hammerstones were found together
as a group 100 m west of Locus 1

Preforms

Easily the most impressive artifacts at those loci which have them are the broken or abandoned boulders that were being flaked. The term "preform" is used to describe these artifacts in recognition of their stage or position in the reduction process, and the fact that it is clear what type of artifact they were to become. Survey data indicate that approximately 35 percent of the production loci contain preforms, most of which are metate preforms with occasional pestle preforms. No preforms were positively identified as mortars or mullers (manos), although finished examples of these artifacts were present in the private museum collection of the McShans in Needles, and were reported in the ethnographic literature for the Mohave Indians. One possible muller preform was present at Locus 5a; it was a long, narrow, relatively thin flake that had been bifacially flaked.

A total of 331 metate preforms was identified by the BLM survey of the quarry area, representing essentially the entire reduction continuum from incipiently flaked boulders to preforms completely shaped by flaking and partially pecked as well. If the "macroflakes" themselves are impressive in terms of size, consider encountering a flaked preform measuring three-fourths of a meter long and half that much in width. Figure 3 presents a selection of preforms abandoned at the quarry, and these may help convey an impression of their size and configuration. The metate preforms tend to be ovoid to subrectangular in plan view; lateral and longitudinal cross sections are generally subrectangular. The more completely flaked the preform, the closer to being completely rectangular in plan and section it will be. While no systematic recording of the metric or nonmetric attributes of the preforms was done in the course of the BLM survey, occasional length and width measurements were taken. Coupled with similar measurements from loci investigated by the Arizona State Museum, length and width measurements for a total of 44 preforms were obtained, and allowed the construction of Figure 4. These data show a strong tendency for preforms to cluster in the size range of 40 cm to 100 cm in length by 25 cm to 60 cm in width, with length exceeding width on all but two specimens. Note that there are two small groupings that fall outside this cluster. There are three preforms that are less than 36 cm long and 31 cm wide; it may be that these were rejected as being too small, or, less likely, that they were intended to be finished into smaller metates. Two very large preforms in excess of 100 cm long and 90 cm wide also fall outside the cluster, and serve to demonstrate that the artisans were not afraid to tackle very large boulders of suitable material. Unfortunately, data on preform thickness were gathered at only 19 loci; a range of 8.5 cm to 45.0 cm was documented, with a mean thickness of 23.2 cm.

The preforms are also of value in determining the lines along which the flaking process proceeded, for they were broken or aborted at different points in this process. The inferred reduction strategy utilized in the production of these metates will be discussed in detail in a later section. Suffice it for now to say that based upon the

Figure 3. Photographs (a-d) and drawings (e-f) of metate preforms broken or abandoned in various stages of manufacture.

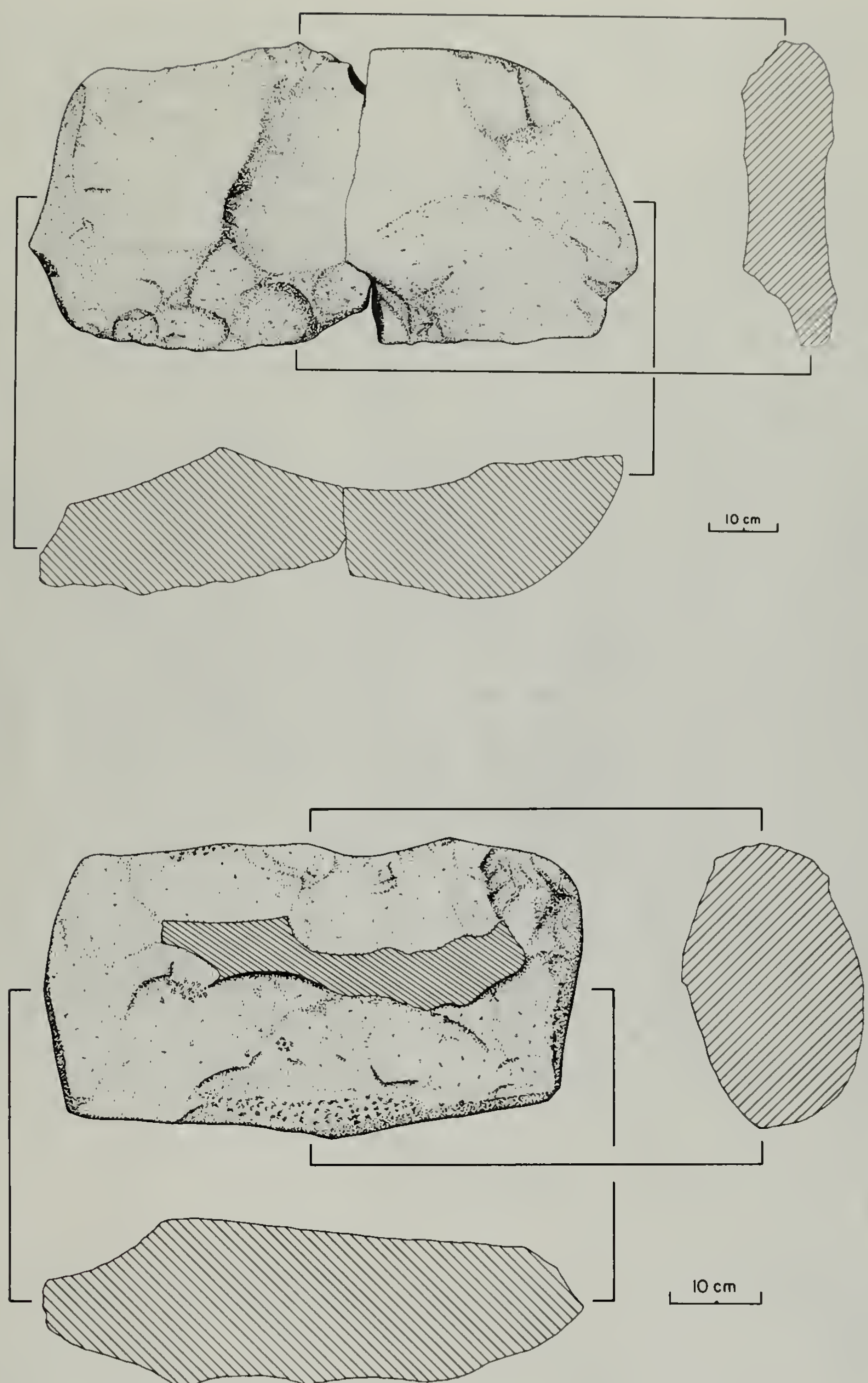

Figure 3 e-f.

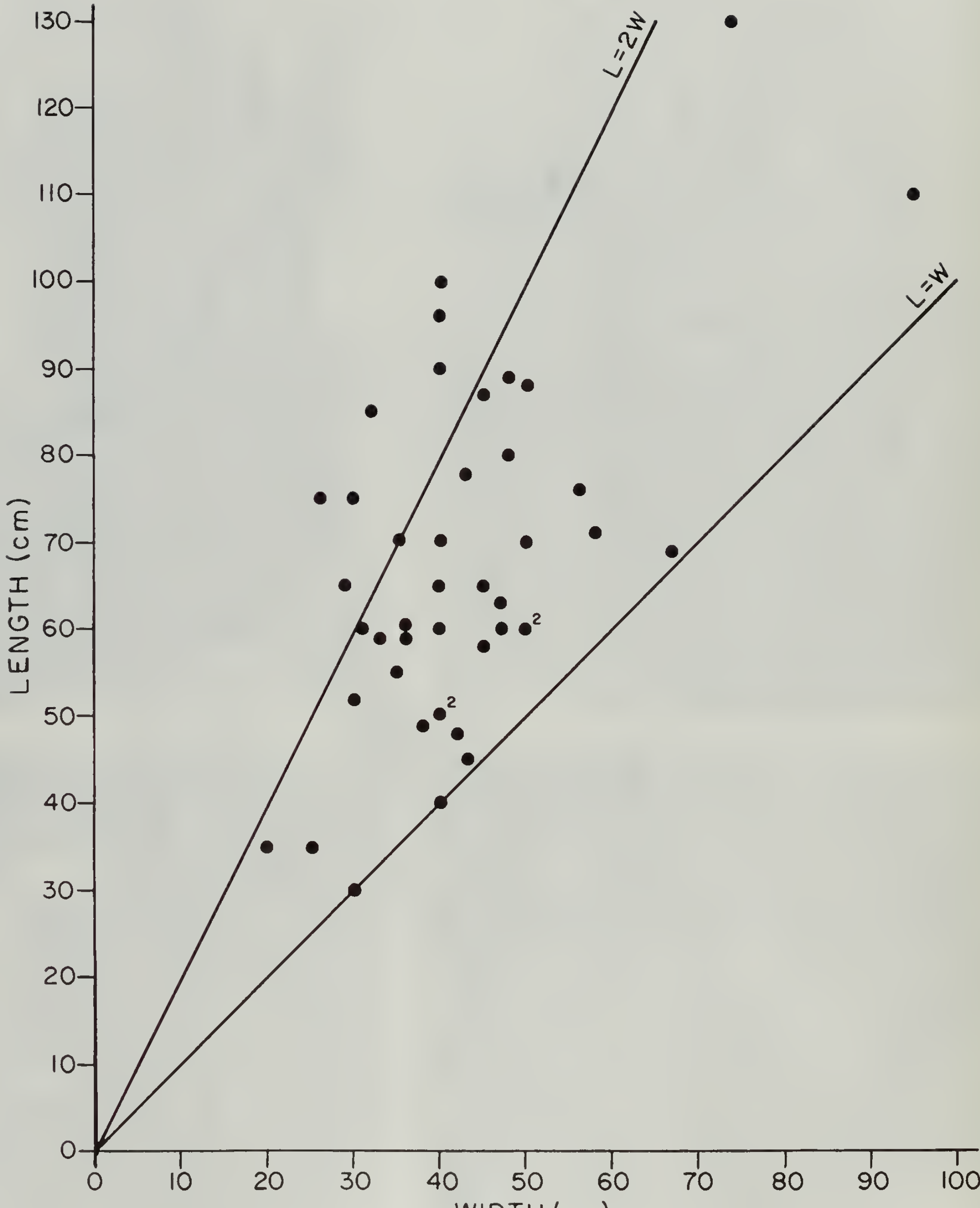

Figure 4. Length to width relationships for metate preforms at the Big Bend Quarry.

preforms, it appears that the artisans first flaked the surfaces of the boulder that were to become the grinding surface and the resting surface, and then flaked the sides and ends of the boulder to produce the desired rectangular shape.

Occurring less frequently are preforms for pestles; an exact total for the number of pestle preforms encountered during survey is not available, but apparently their numbers represent less than 5 percent of the number of metate preforms encountered. The pestle preforms are generally made of a less vesicular grade of andesite or are occasionally of other porphyrytic igneous materials. Also shaped by flaking, they too exhibit a range in the amount of work done before they were broken or abandoned. On only nine pestle preforms were measurements taken; these are shown on Figure 5. All of these are at least twice as long as they are wide, and all but two are more than 35 cm long. These two shorter specimens are approximately 25 cm in length, which seems extremely short for the sizes of pestles known from this area both archaeologically and ethnographically. It is possible, therefore, that these are instead mano or muller preforms rather than pestle preforms. Thickness measurements tend to be within 2 cm to 4 cm of the width measurements for the pestle preforms, although the possible mano or muller preform at Locus 5a is only 6.5 cm thick. No systematic study of pestle reduction strategy was undertaken in this project. However, study of the two investigated loci, and examination of broken pestle preforms at the San Bernardino County Museum and the McShans' private museum, permit a general statement. The main flaking effort was done along the long margins of naturally elongate cobbles, resulting in the creation of bifacially flaked surfaces in most cases. Sometimes trifacial or even four unifacial flake series were removed from three or four striking platform surfaces respectively. The ends of the cobbles were also flaked in unifacial or bifacial fashion to produce a convex or rounded shape. The main effort seems to have been to create as nearly cylindrical a cross-section as possible over the entire length of the cobble. This was followed by pecking for final shaping and finishing.

Hammerstones

Survey of the quarry areas by BLM archeologists disclosed the presence of 771 hammerstones, usually found in direct association with the production loci. The majority of these took the form of quartzite river cobbles which displayed one unifacially flaked end or edge with obvious battering and spalling along the retouched end or edge. Also present were nonvesicular igneous cobbles, which were usually characterized by one or two battered and occasionally spalled or flaked ends. These did not display the carefully retouched edges of their quartzite counterparts. Porphyrytic igneous cobbles were also observed to have been used as hammerstones, though these were rare. The quartzite cobbles, as mentioned above, are nonlocal to the Black Mountains bajada, but may be found in great quantity on terraces that border the historic floodplain of the Colorado River and exposed in drainages cut into these terraces. The igneous cobbles, however, are found scattered over the bajada surface, and presumably have their origins in the Black Mountains.

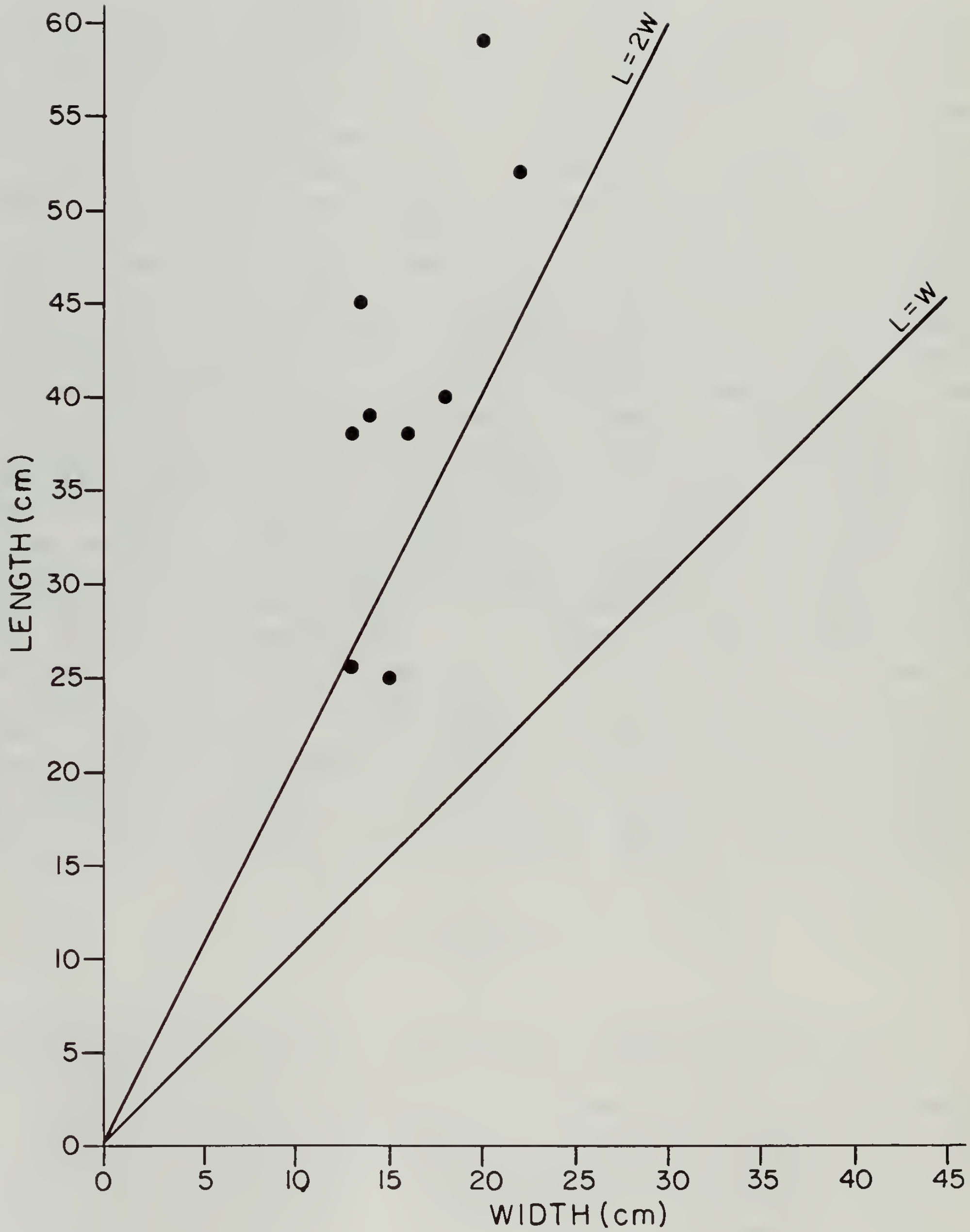

Figure 5. Length to width relationships for pestle preforms at the Big Bend Quarry.

Systematic metric and nonmetric data were not collected from the hammerstones during the BLM survey; the data obtained from the 33 hammerstones found in association with the loci included in this study are the only source of such information on these artifacts. Of the 33 hammerstones, 22 (64.7%) are of quartzite, 11 (32.4%) are of basalt or andesite, and 1 (2.9%) is of porphyrytic igneous material. It should be noted that these figures may be somewhat misleading, in that there may be a tendency for the material type data to be skewed in favor of quartzite . This is true not only because of the small sample size, but because that it is easy to overlook the igneous hammerstones. Being of local rock, they have a tendency to blend in with the natural surface of the bajada, particularly when they have not been flaked or spalled. Quartzite hammerstones, all of light colors and usually without desert varnish, tend to stand out against the bajada surface and may therefore be somewhat overrepresented.

In addition to differences in material type, there are differences in the sizes of the hammerstones as well; Figure 6 shows length and width measurements plotted by material type for the small sample of measured hammerstones. The figure shows that there is a clear tendency for the igneous hammerstones to be larger than the quartzite. This size difference, coupled with the differences in retouch and wear noted above, suggests that there may be two types of hammerstones at these loci. Large, battered, unretouched hammerstones of igneous rock may have served primarily as percussion hammers for initial flaking, while the smaller, unifacially retouched hammerstones of quartzite may have seen use for the removal of smaller flakes and as pecking hammers in the final finishing process. As will be discussed in a later section, experimentation has shown that large, unretouched hammerstones of either quartzite or igneous rock are efficient tools for removal of large flakes, but that unifacially retouched hammerstones are slightly less useful for this task. However, the narrow, wedge-shaped, retouched edge of these hammers may possess certain advantages over the broad, rounded ends of the unretouched ones. That is, they may serve to allow precise blows to be delivered to narrow or small platforms inaccessible to larger, broader hammers. This could include preparing striking platform areas by pecking, or utilizing step fracture flake terminations as striking platforms, both as suggested by Cerutti (1984) in a study of pestle manufacture in the Picacho Basin of California. Further, it is interesting to note that until 1950 Highland Maya metate makers employed retouched cobble hammerstones to shape metates of vesicular basalt (Hayden and Nelson 1981). Such tools are used for both flaking and pecking and are either unifacially or bifacially flaked. Thus it is possible that the retouched quartzite cobble hammerstones also served for both flaking and pecking tasks at the Big Bend quarry. As a final note, it may be that hammerstones, especially those used for flaking, were not left at the loci if they were viewed as still having functional value. They may have been reused at other loci. In some cases, flakes of other materials, probably from quartzite hammerstones, were present at loci which did not contain either a preform or hammerstones, suggesting that the latter had been removed after a successful flaking operation.

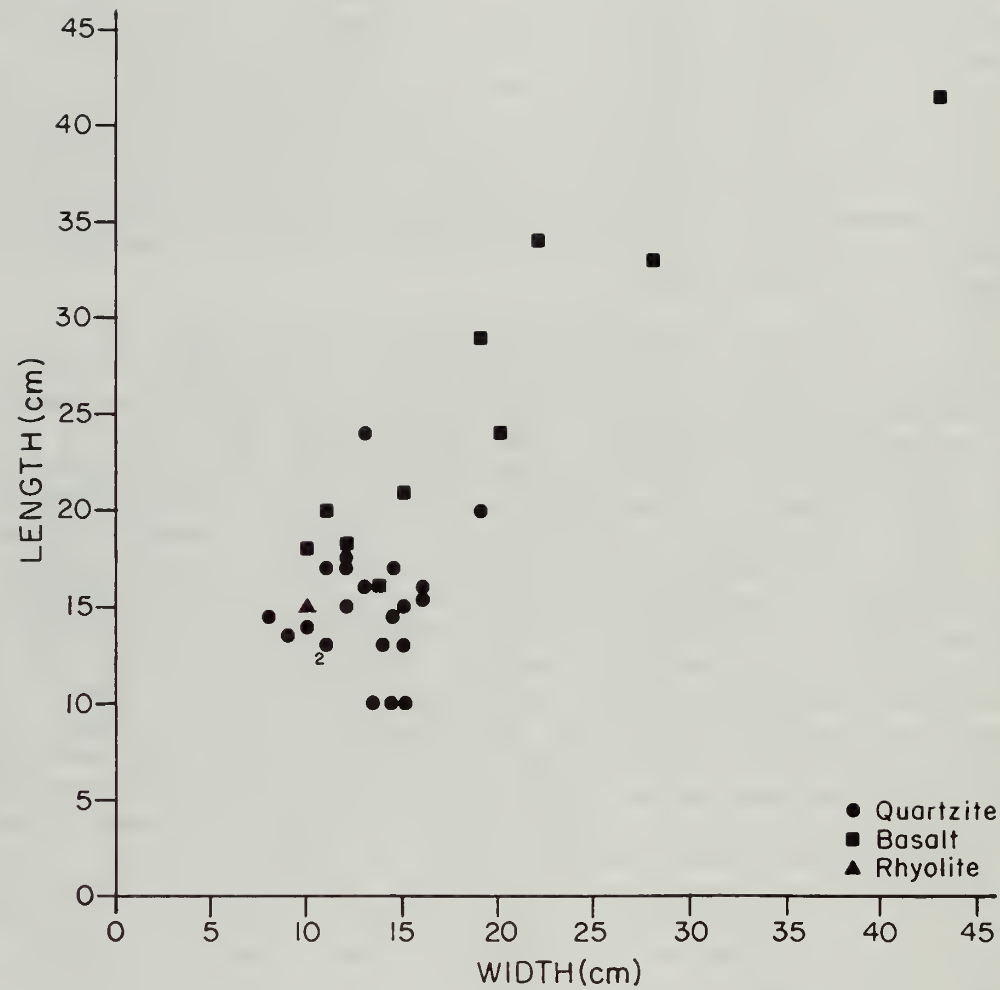

Figure 6. Length to width relationships for hammerstones at the Big Bend Quarry.

Bracing Rocks or "Anvils"

Occurring at the production loci were local igneous rocks that had clearly been manipulated, but in most cases had not been flaked. The BLM archaeologists recognized them by virtue of obviously fresh scratches or abrasions that cut through the desert varnish coatings on their surfaces, occasional flakes or spalls removed from them, and, in some cases, their positions underneath abandoned preforms where they had been intentionally placed by the artisans. Because they were not recognized as distinctive until after a considerable amount of survey had been performed, their presence was sought only in about 50 percent of the area examined, according to Boma Johnson. A total of 225 was recorded in that half of the survey area examined after these stones were recognized as an artifact type. The surveyors referred to them as "anvils," suggesting that they functioned to prop up boulders being flaked, possibly also aiding in the process by providing a firm surface against which flaking could occur (BLM 1984). The term "bracing rock" is suggested in place of anvil, for it appears that most of these rocks functioned only to position the boulder being worked at the angle most convenient for the artisan to remove flakes. This too is discussed in more detail in a later section dealing with experimentation.

"Punches"

Ninety-one artifacts were identified by the BLM surveyors as "punches," elongated rocks which were naturally pointed or deliberately shaped on one end and showed evidence of having been struck on the opposite end. They were interpreted to have functioned as punches for more controlled flaking using indirect percussion technique. Like bracing rocks, they were only recognized after a good deal of the survey had been completed, and so were actually sought in only 38 percent of the area examined, according to Boma Johnson. The suggested use of indirect percussion is based upon experimental work by Cerutti (1984) aimed at replication of manufacturing techniques used in the production of "basalt cylinders" at a quarry site in the Picacho Basin of California. Cerutti found that this technique could be used when direct percussion was not possible. Consisting of first pecking a depression into an edge or surface to serve as a striking platform, the technique employs a stone punch, seated in the pecked depression, which is struck with a stone hammer to remove a flake. One specimen identified in the field as a punch was collected by Arizona State Museum archaeologists. It is an elongated, porphyrytic igneous cobble with flaking at one end and along part of one edge, and battering and spalling at the other. The flake scars on the end and edge display pronounced, well formed bulbs of percussion, which suggest that these flakes were intentionally removed. Flakes removed accidentally are more likely to display cone shear fractures, leaving flat scars lacking prominent bulbs of percussion. It further seems that materials such as this fine grained porphyry are too prone to spalling to make reliable punches, and experimentation by this author has not shown indirect percussion to be a useful technique in the primary reduction of large boulders.

However, it is possible that this technique could serve the function that Cerutti notes: recovery from manufacturing errors or irregularities in the preform. There is no question that the artisans had the knowledge to create striking platforms by pecking; one example of this is present on the preform from Locus 7 (Fig. 3e). However, whether indirect or direct percussion was used to remove the flake struck from that created platform is open to question. Further, the sample of debitage and preforms examined in this study indicates that this practice was rare at the Big Bend Quarry, suggesting that it constitutes an infrequently employed technique. At present, it seems best to view indirect percussion with a punch as a technique possibly, but not certainly, employed by the artisans at this quarry. Only by examining a large sample of these so-called punches and further experimentation will it be possible to evaluate the existence and utility of this technique at the Big Bend Quarry.

Debitage

Table 2 presents summary statistics for the nonmetric attributes of the debitage recorded at the 10 loci studied by the Arizona State Museum and the one collected by the BLM. There is a fairly wide range of variability present in the expression of some of the attributes, and some overall or general consistency in others.

First, it is noteworthy that the number of flakes at a given locus can vary widely; loci representing the apparently successful manufacture of a metate preform contain from 88 flakes at Locus 3c to 160 flakes at Locus 2. At Loci 10a and 10c, which probably represent spatially separate reduction areas for a single boulder, a combined total of 186 flakes was recovered and a few flakes were noted to be thinly scattered between the two loci. At Locus 11, a metate preform was broken during the pecking process after the flaking had been completed; a total of 105 flakes was present here. It must also be remembered, however, that these figures include both complete and fragmentary flakes. In order to accurately determine how many flakes were actually removed, one would have to engage in time-consuming refitting of fragments. Because this was not possible in this case, a rough approximation of the total number of flakes was obtained by combining the number of complete flakes and one-half the number of fragmentary flakes at each locus. The assumption here is simply that most of the fragmentary flakes had been broken into two pieces; the validity of this assumption is not known. Still, it provides a means by which one can evaluate how many flakes may have been detached during the flaking process. Using this method, an estimated 60 to 140 flakes may represent the range of how many flakes needed to be removed from a boulder to complete a flaked metate preform. This range of variation is based on the investigated loci; the exact number of flakes removed would naturally be dependent upon the initial size of the boulder and how successfully the reduction strategy was executed. Failed reduction efforts, however, can produce a wider range of numbers of flakes, depending upon when the reduction process was stopped by either breakage

Table 2

NONMETRIC ATTRIBUTES OF THE DEBITAGE
FROM INVESTIGATED PRODUCTION LOCI

Locus			Condition		Platform			Cortex**				Exterior Flake Scars**						
		N	Complete	Fragment	Cortical	Plain	Dihedral	Faceted	75-100%	50-74%	25-49%	0-24%	0	1	2	3	4	5	6
1	Count	102	73	29	27	54			31/40	3/6	1/1	38/55	29/38	22/30	16/27	6/7			
	% Flakes		71.6	28.4	33.3	66.7			39.2	5.9	0.9	53.9	37.3	29.4	26.5	6.9			
	% Complete Flakes								42.5	4.1	1.4	52.1	39.7	30.1	21.9	8.2			
2	Count	160	115	45	124	20	2	1	56/84	11/15	11/14	37/46	54/82	32/39	23/28	4/4	2/3		
	% Flakes		71.9	28.1	84.4	13.6	1.4	0.7	52.8	9.4	8.8	28.9	52.6	25.0	17.9	2.6	1.9		
	% Complete Flakes								48.7	9.6	9.6	32.2	47.0	27.8	20.0	3.5	1.7		
3c	Count	88	38	50	20	32			7/14	6/7	4/7	21/60	4/9	13/46	12/23	9/10			
	% Flakes		43.2	56.8	38.5	61.5			15.9	8.0	8.0	68.2	10.2	52.3	26.1	11.4			
	% Complete Flakes								18.4	15.8	10.5	55.3	10.5	34.2	31.6	23.7			
4a*	Count	41	24	17	1	29			1/4	1/2	0/3	22/32	0/2	6/13	8/13	8/11	2/2		
	% Flakes		58.5	41.5	3.3	96.7			9.8	4.9	7.3	78.0	4.9	31.7	31.7	26.8	4.9		
	% complete Flakes								4.2	4.2		91.7		25.0	33.3	33.3	8.3		
5a	Count	128	65	63	51	22		2	20/31	5/8	8/11	32/78	15/24	20/52	19/36	8/12	3/4		
	% Flakes		50.8	49.2	68.0	29.3		2.7	24.2	6.3	8.6	60.9	18.8	40.6	28.1	9.4	3.1		
	% Complete Flakes								30.8	7.7	12.3	49.2	23.1	30.8	29.2	12.3	4.6		
5b	Count	16	11	5	9	3			4/5	1/1	1/1	4/7	4/6	4/6	2/3		1/1		
	% Flakes		68.8	31.3	75.0	25.0			35.7	7.1	7.1	50.0	42.9	42.9	21.4		7.1		
	% Complete Flakes								40.0	10.0	10.0	40.0	36.4	36.4	18.2		9.1		

Table 2, continued

NONMETRIC ATTRIBUTES OF THE DEBITAGE
FROM INVESTIGATED PRODUCTION LOCI

Locus		N	Condition		Platform				Cortex**				Exterior Flake Scars**						
			Complete	Fragment	Cortical	Plain	Dihedral	Faceted	75-100%	50-74%	25-49%	0-24%	0	1	2	3	4	5	6
6	Count	47	12	35	16	5			6/23	1/5	2/5	3/13	3/10	7/31	1/3	0/1	1/1		
	% Flakes		25.5	74.5	76.2	23.8			50.0	10.9	10.9	28.3	21.7	67.4	6.5	2.2	2.2		
	% Complete Flakes								50.0	8.3	16.7	25.0	25.0	58.3	8.3		8.3		
7	Count	245	81	164	26	99	3		14/26	3/16	9/22	55/179	11/19	27/128	26/70	8/12	8/12	1/1	0/1
	% Flakes		33.1	66.9	20.3	77.3	2.3		10.7	6.6	9.1	73.7	7.8	52.7	28.8	4.9	4.9	0.4	0.4
	% Complete Flakes								17.3	3.7	11.1	67.9	13.6	33.3	32.1	9.9	9.9	1.2	
8*	Count	34	14	20	11	10			2/8	7/10	2/7	3/9	2/7	6/18	6/9				
	% Flakes		41.2	58.8	52.4	47.6			23.5	29.4	20.6	26.5	20.6	52.9	26.5				
	% Complete Flakes								14.3	50.0	14.3	21.4	14.3	42.9	42.9				
9	Count	44	11	33	9	16	1		6/12	1/2	0/3	4/27	2/4	6/26	2/11	1/3			
	% Flakes		25.0	75.0	34.6	61.5	3.8		27.3	4.5	6.8	61.4	9.1	59.1	25.0	6.8			
	% Complete Flakes								54.5	9.1		36.4	18.2	54.5	18.2	9.1			
10a	Count	128	44	84	38	16			9/15	2/6	4/12	29/94	6/10	10/52	12/37	8/15	5/8	2/2	1/3
	% Flakes		34.4	65.6	70.4	29.6			11.8	4.7	9.4	74.0	7.9	40.9	29.1	11.8	6.3	1.6	2.4
	% Complete Flakes								20.5	4.5	9.1	65.9	13.6	22.7	27.3	18.2	11.4	4.5	2.3
10b	Count	15	7	8	6	7						7/15		2/5	1/4	4/6			
	% Flakes		46.7	53.3	46.2	53.8						100.0		33.3	26.7	40.0			
	% Complete Flakes											100.0		28.6	14.3	57.1			

Table 2, continued

NONMETRIC ATTRIBUTES OF THE DEBITAGE
FROM INVESTIGATED PRODUCTION LOCI

Locus		N	Condition		Platform				Cortex**				Exterior Flake Scars**						
			Complete	Fragment	Cortical	Plain	Dihedral	Faceted	75-100%	50-74%	25-49%	0-24%	0	1	2	3	4	5	6
10c	Count	58	28	30	20	16			8/10	2/4	5/6	13/38	7/9	11/30	9/18	1/1			
	% Flakes		48.3	51.7	55.6	44.4			17.2	6.9	10.3	65.5	15.5	51.7	31.0	1.7			
	% Complete Flakes								28.6	7.1	17.9	46.4	25.0	39.3	32.1	3.6			
11	Count	105	56	49	14	53	2		12/9	15/12	8/6	70/29	8/5	39/20	35/15	17/11	6/5		
	% Flakes		53.3	46.7	20.3	76.8	2.9		11.4	14.3	7.6	66.7	7.6	37.1	33.3	16.2	5.7		
	% Complete Flakes								16.1	21.4	10.7	51.8	8.9	35.7	26.8	19.6	8.9		

* Pestle production locus
** (complete/fragments)

or conscious decision. For example, a decision to abandon the effort early in the reduction process, such as at Locus 6 or 9, left clusters of only 47 and 44 total flakes respectively. That would mean that only an estimated 29 and 27 actual flakes were removed, respectively, at these loci. In contrast there is Locus 7, where the artisans conceded failure only after removing 245 total flakes (representing an estimated 160 flakes) from one boulder.

How many flakes might be needed to be removed to produce a pestle preform is uncertain; the two failed efforts at Loci 4a and 8 left only 41 and 34 total flakes, respectively. The work at Locus 8 ended with the breakage of the preform, and a decision was apparently made to abandon the preform at Locus 4a. No loci were identified that could be confidently interpreted as representing the successful manufacture of a pestle preform. An admittedly rough estimate is that between 40 and 80 complete flakes might result from a successfully flaked pestle preform.

Table 2 also indicates that flake condition or completeness varies a good deal; some loci display ratios of 2.6 complete flakes for every fragment, while others show only one complete flake for every three fragments. A number of factors may influence this ratio, including the shape and lithologic characteristics of certain boulders, the skill of the artisan, types and sizes of flakes being removed, and post-detachment breakage produced by flakes falling against bracing rocks, being trampled underfoot, or broken during manipulation of the preform. Further, it is frequently difficult to assess a flake's completeness, due to the coarse grain size of the material, often weakly developed bulbs of percussion, crushing of striking platform surfaces, and often irregular flake terminations. Thus, there is room for a small amount of analytical error based on the skill of the observer and his familiarity with the material.

Striking platforms present on the flakes from the loci are almost exclusively cortical or plain (that is, a featureless noncortical surface; Table 2). Only eight dihedral (having two intersecting facets) striking platforms and three faceted (having three or more intersecting facets) ones were identified in the entire sample of 696 platforms that was studied. However, the relative numbers of cortical and plain striking platforms may be seen to vary from loci where cortical platforms are dominant (Loci 2, 5a, 5b, 6, and 10a) to loci where plain platforms are dominant (Loci 1, 3c, 4a, 7, 9, and 11) to loci where they are almost equal in numbers (Loci 8 and 10b). Variation in the relative frequencies of these platform types may be ascribed to two factors: (1) the success with which cortical surfaces are removed in the initial phases of reduction, and (2) the amount of reduction effort necessary to complete a particular metate or pestle preform. As will be discussed below, the usual reduction strategy apparently employed by the artisans was centered around the removal of large, primary, cortical flakes from the boulders; from their point of view, the fewer such flakes needed to clear the surfaces of the boulder, the better. Thus, efficient reduction using this technique would tend to produce fewer, larger, more cortical flakes, leaving more plain surfaces to serve as striking

platform surfaces for the removal of flakes along the sides and ends of the boulder. Locus 11 (Table 2) illustrates such a pattern quite nicely. Inefficient reduction, caused either by the relative skill of the artisan or the configurational peculiarities of a given boulder, could produce more, smaller, cortical flakes before large areas of plain surfaces were created. In addition, the amount of work needed to produce a preform from a given boulder should cause similiar variation in platform type frequency. That is, once the cortex is removed subsequent reduction must be done from noncortical plain, dihedral, or faceted striking platform surfaces. Locus 7 (Table 2) serves as a prime example; extensive reduction was needed to reduce the thickness of the boulder, and as a result there are nearly four flakes with plain striking platforms for every flake with a cortical platform. As the refitting of flakes to the preform demonstrates, a poor initial series of primary decortication flakes (all short and ending in hinge fracture terminations) on one surface caused the subsequent problems (Fig. 7).

As may also be seen from Table 2, data regarding the relative percentage of exterior surface cortex and the number of previous flake scars are presented in two forms: one set of figures for all flakes from a particular locus, and one for just the complete flakes from that locus. This is done because, depending upon how a flake is broken, the resulting fragments may not accurately reflect the amount of cortex or the number of scars present on what would have been the complete flake. Using only complete flakes resolves this problem. However, if one views only the complete flakes, there is no guarantee that they accurately

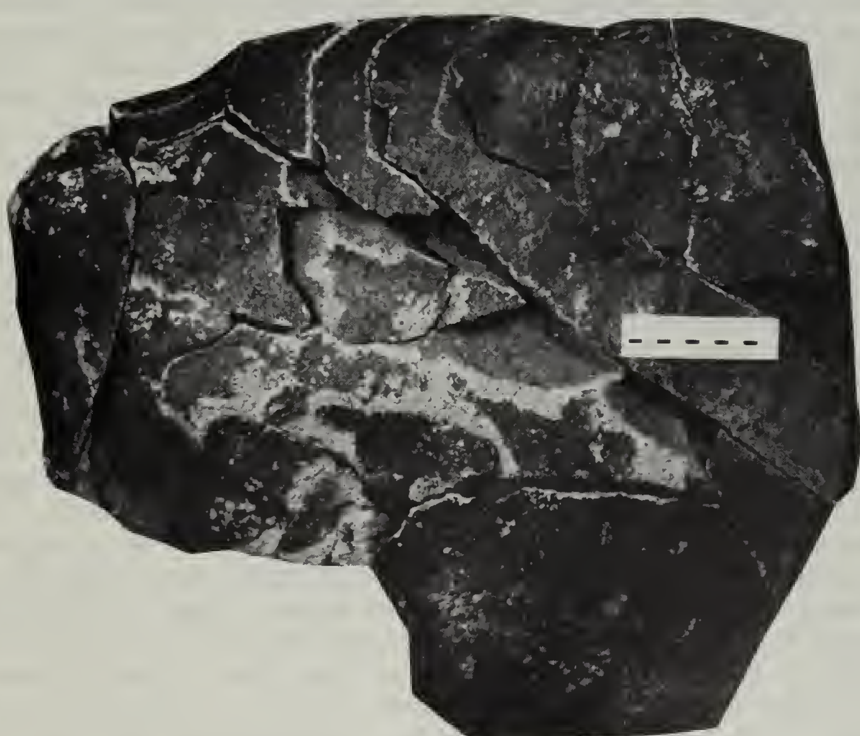

Figure 7. Aborted metate preform from Locus 7 with flakes refitted. The poor initial flake series at the top of the photo did not carry sufficiently far across the boulder surface to thin it, instead stopping short and ultimately leading to a manufacture failure.

represent the debitage as a whole; in other words, flake breakage cannot be assumed to be random, and certain cortical classes and flake scar categories may be prone to differential breakage rates. Because this dilemma cannot be resolved for the Big Bend Quarry site material at this time, data for both complete flakes and all flakes are presented in the table. Perusal of the table will show that correspondence between these two data sets within a locus varies from relatively high (Locus 6) to relatively low (Locus 9), and may also vary between cortex class and scar count within a given locus.

Turning to cortex class, it may be seen that regardless of which set of data is examined, all loci except Locus 8 show a predominance of flakes with 75 to 100 percent cortex and flakes with 0 to 24 percent cortex; flakes with 25 to 49 percent cortex and 50 to 74 percent cortex are relatively far less abundant, generally constituting less than 20 percent of the debitage at any locus. Locus 11 is somewhat exceptional in that flakes with 50 to 74 percent cortex are slightly more abundant than flakes with 75 to 100 percent cortex. Generally speaking, the relative proportions of cortex classes are probably also a function of the success with which the cortical surfaces were removed and the relative amount of flaking needed to complete a particular metate or pestle preform. These are the same factors suggested as important in determining the relative proportions of cortical and noncortical striking platforms. As noted above, efficient serial removal of the cortex with large, single flakes will produce a few large cortical flakes with 75 to 100 percent exterior cortex, or 50 to 74 percent cortex, depending upon the degree to which such a series of flakes laterally overlap with one another. The amount of lateral overlap is important because more widely spaced blows during the initial stage of reduction will produce less overlapping and therefore more exterior cortex on each individual flake. More closely spaced blows will have just the opposite effect.

The percentages of the cortex classes at Locus 6 and Locus 7 illustrate the effects of the relative amount of reduction done on a particular preform. At Locus 6, a metate preform abandoned at an early stage of reduction, there is a clear predominance of highly cortical flakes. Note also that Locus 2, an apparently successful metate production locality, is also dominated by highly cortical flakes, suggesting that the cortex was not removed by a few large flakes, but rather with many smaller ones, and that relatively little flaking needed to be done after the cortical surfaces were removed. At Locus 7, a preform abandoned after extensive reduction efforts, there is a predominance of flakes with little or no cortex. An extreme example is Locus 10b, where a metate preform was apparently being finished; only flakes of the 0 to 24 percent cortex class were present there. Thus, the more reduction that is needed, the higher will be the relative amount of flakes in the 0 to 24 percent cortex class. The relative paucity of flakes in the 25 to 49 percent and 50 to 74 percent classes is apparently a function of an efficient reduction strategy and the relative amount of reduction work needed to complete a preform.

The final attribute presented in Table 2 is previous flake scar count. As the data show, there is a general tendency for flakes with

one previous flake scar to be the most abundant, followed closely by those with two scars; Loci 3c, 5a, 7, 8, 10a, and 11 exemplify this pattern. Three other loci--1, 2, and 5b--follow a slightly different pattern, having flakes with no previous flake scars on their exterior surfaces forming the dominant class. However, only at Locus 2 are such flakes markedly more abundant, and in all cases flakes with one previous scar are the next most common class. It is suspected that these two patterns are the product of reduction efficiency, with the abundance of flakes with no previous scars being related to the size and spacing of flakes in the initial reduction series and to the size of the original boulder. A further observation is that flakes with more than three previous flake scars are generally quite rare, and that no more than six previous flake removal scars were ever observed on a single flake. From these observations it is possible to conclude that the reduction strategy was focused on the removal of as few flakes as possible to achieve the desired results, and that an approach such as removing a series of smaller flakes to create a core face of suitable configuration for the removal of one or two larger flakes was not viewed as a practical or desirable strategy. This is probably a reflection of the flaking characteristics of the material, for in my experience coarse-grained materials are generally best flaked with single, well spaced, large flake removal blows. Lighter, more closely spaced blows invite undesirable results such as crushed striking platforms, step or hinge fracture terminations, and flakes which simply do not yield the desired results.

Measurements of the length, width, and thickness of complete flakes at the 11 loci leave no doubt that some are truly "macro" flakes. Flakes measuring in excess of 20 cm in both length and width are not uncommon, and some over 30 cm long by over 40 cm wide were recorded. Of course, numerous smaller flakes less than 5 cm long by 5 cm wide were also present at most loci. Figure 8 presents, in graphic form, length, width, and thickness measurements for five selected loci. Note that these graphs do not portray absolute length and width but rather a series of 2.5 cm size classes; thus the intervals are 0 to 2.5 cm, 2.5 cm to 5 cm, 5 cm to 7.5 cm, and so on. For thickness the intervals are reduced, and this dimension is presented in 0.5 cm classes (0.5 cm to 1.0 cm, 1.0 cm to 1.5 cm, and so forth). These particular loci were chosen because they represent two apparently successful metate preform production efforts (Loci 1 and 2), an almost successful reduction effort (Locus 11), a late reduction stage failure (Locus 7), and an early reduction stage failure (Locus 6).

As Figure 8 indicates, there is little consistency among the metate production loci in the distribution of flake size classes for either length or width. Both Loci 1 and 2 show a predominance of flakes in Size Classes 2, 3, and 4, and there are particularly sharp peaks in Size Class 2 flakes for both length and width. In short, flakes 2.5 cm to 5.0 cm in length and width are most abundant, especially at Locus 1; Locus 2 contains relatively more flakes in Size Classes 3 and 4 (5 cm to 7.5 cm and 7.5 cm to 10.0 cm) than does Locus 1. Locus 7, on the other hand, shows relatively smaller numbers of flakes in Size Classes 2 and 3, although these are still dominant. Flakes of Size Classes 5 through

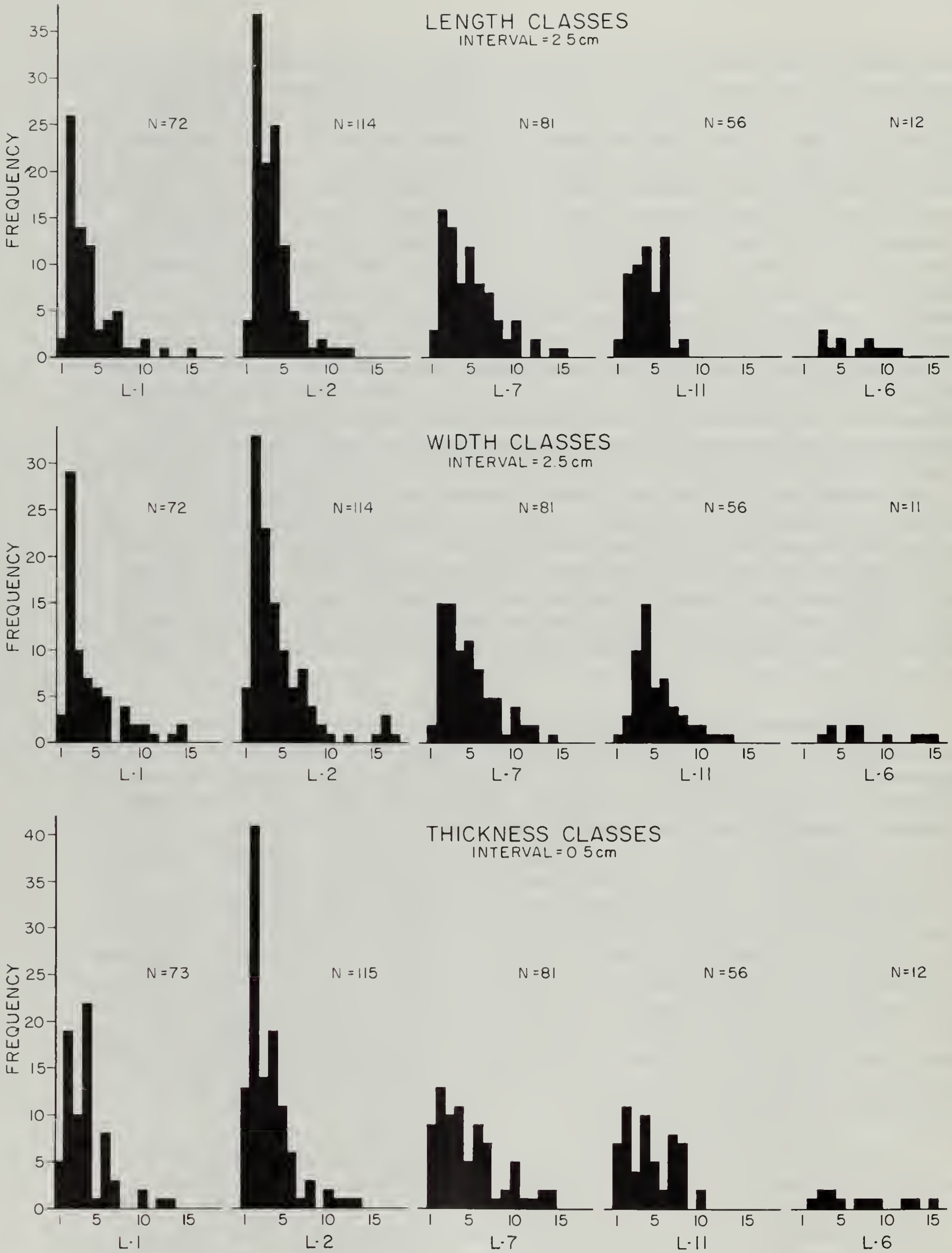

Figure 8. Metric attributes of the flakes from five selected production loci (1, 2, 7, 11, and 6) at the Big Bend Quarry.

8 are more abundant at Locus 7. The same trend toward greater relative abundance of larger flakes is continued at Locus 11; here flakes of Size Classes 4 and larger are most common, particularly in the width dimension. Locus 6 shows little consistency in flake size; a wide range of size categories is represented in both length and width, with only one or two flakes in each category. Flake thickness distributions generally parallel the tendencies observed in length and width for each locus.

While this is an extremely small sample from which to generalize, flake metric attributes seem to have little of value to contribute to the overall understanding of the metate production loci. This is perhaps best shown by comparing the distribution of flake length and width size classes for Loci 1 and 2 with that of Locus 11. All three represent the same manufacturing goal that succeeded or failed at approximately the same point; that is, the reduction by flaking had been finished. Yet, the metric data for flake length and width are very different. Lacking knowledge of the kind of artifact being manufactured one might well suspect that entirely different manufacturing efforts were represented. It may be suggested that relative flake size and abundance of particular classes of flakes will be conditioned by the size and configuration of the original boulder, the reduction strategy employed, and the succcess with which the reduction was accomplished.

Flake dimensional data may be useful in other ways, however, particularly if combined with other attributes. One of the goals of this study was to reconstruct the reduction strategy employed in metate manufacture. Two complementary avenues of approach are appropriate for this task: the study of preforms broken or aborted in manufacture, and debitage. The best conditions are obtained from loci where both a broken or aborted preform and the debitage from that preform are present. The work conducted for this project has allowed the construction of an idealized, standard reduction strategy, which will be discussed in detail in a subsequent section but has been alluded to in the section discussing the metate preforms. Support for this reduction strategy inferred from the preforms may be found when flake length and width are plotted on a graph with each flake coded by cortex class.

In Figure 9 complete flake length and width are plotted by cortex class for each of the five metate production loci discussed above. Note that the expected relationship of flake size and cortex class obtains for Loci 6, 7, and 11, and less well for Locus 1. At these loci, the larger flakes tend to be more cortical, and the smaller flakes less cortical. Locus 6, where a metate preform was abandoned at an early stage of reduction, is particularly instructive, showing a clear separation of large cortical and small noncortical flakes. Locus 11, where a preform was successfully flaked only to be broken during pecking, shows the same general relationship; note that the largest flakes all have at least 50 percent cortex, and that flakes less than 13 cm long by 16 cm wide are largely those with less than 50 percent cortex. The same basic relationship may be seen at Locus 7 as well, where a preform was abandoned only after extensive reduction efforts. Note that there are some relatively large, noncortical flakes here, but

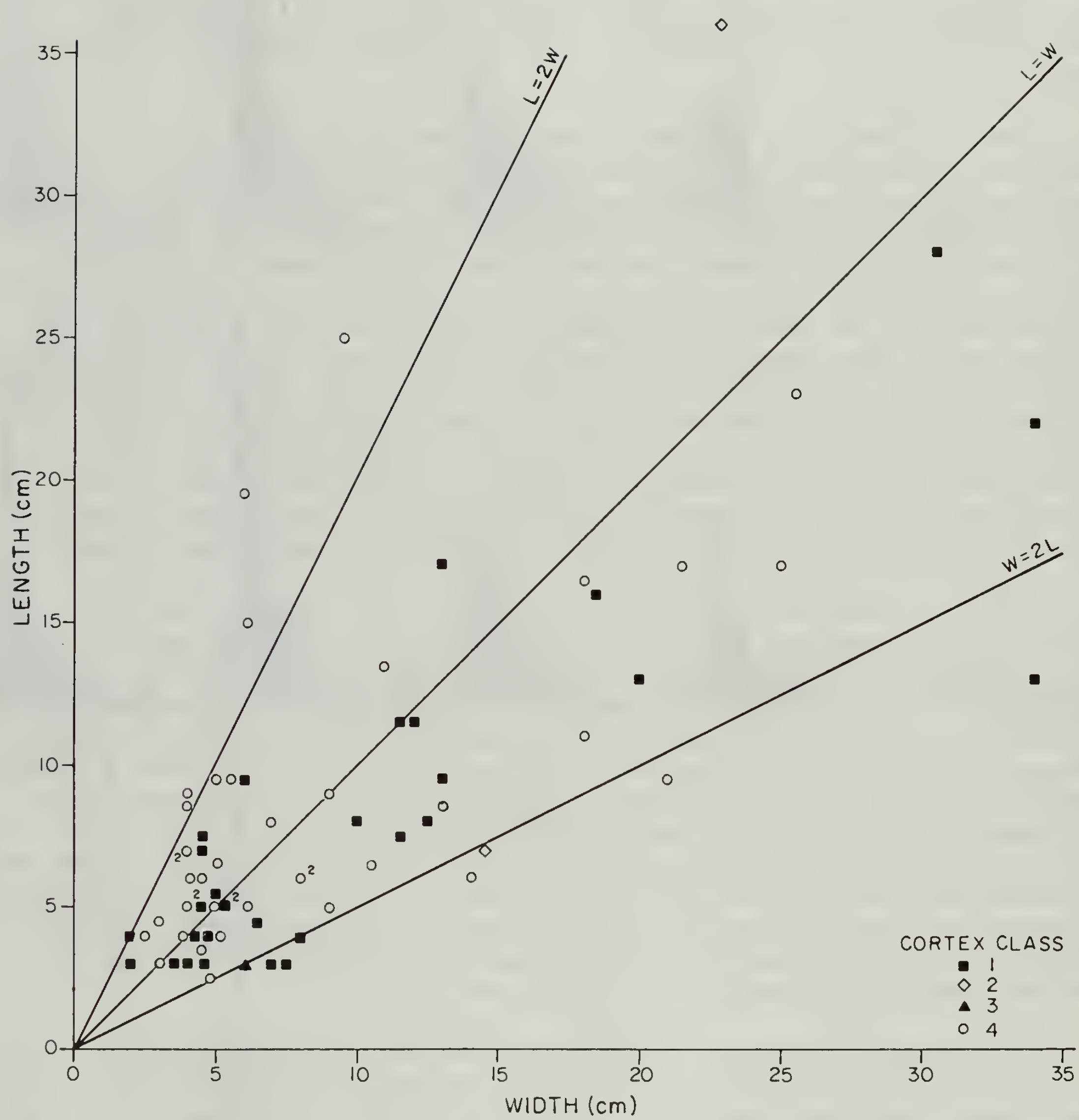

Figure 9. Length and width of flakes plotted by cortex class for Locus 1.

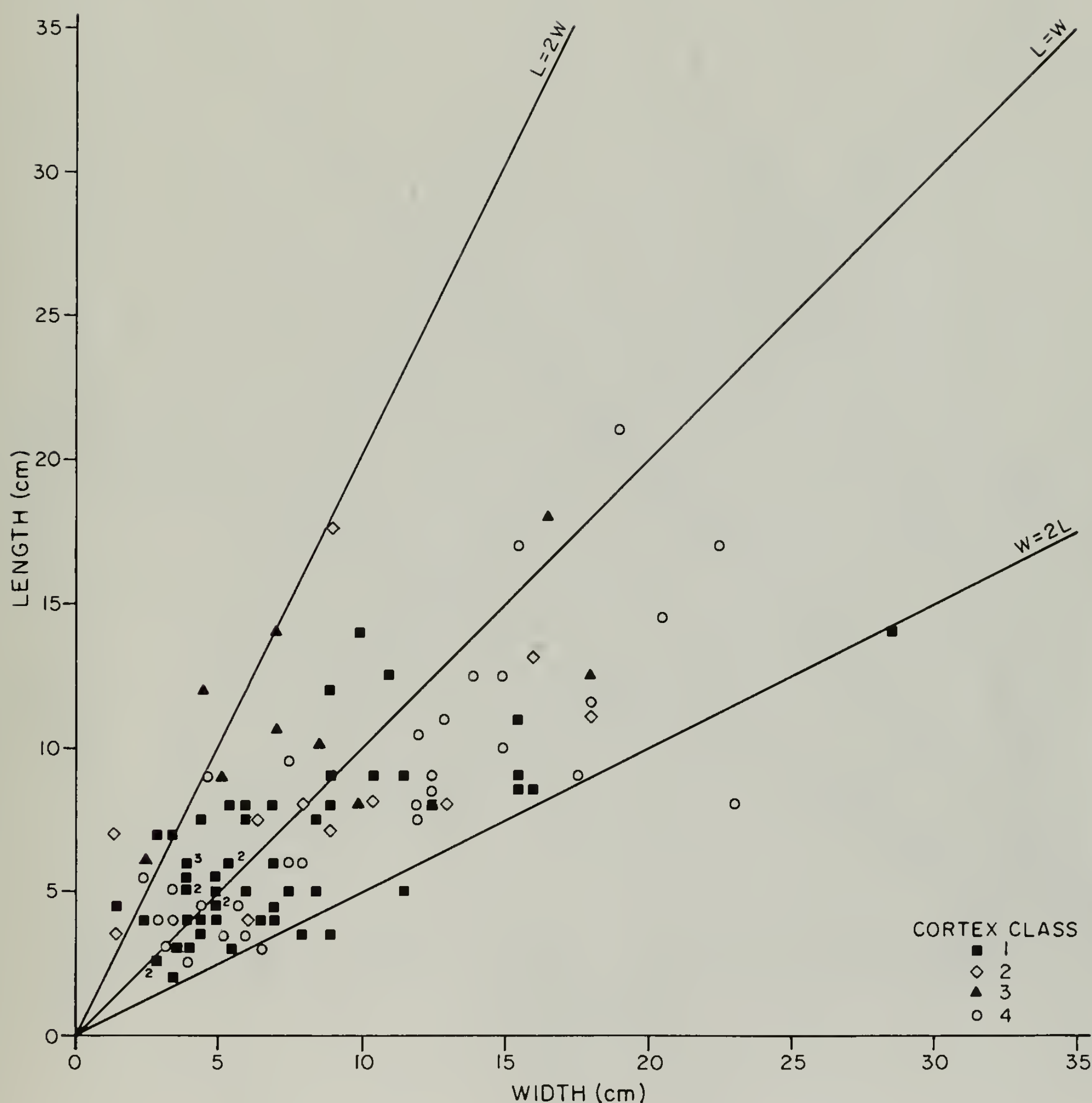

Figure 9. Length and width of flakes plotted by cortex class for Locus 2.

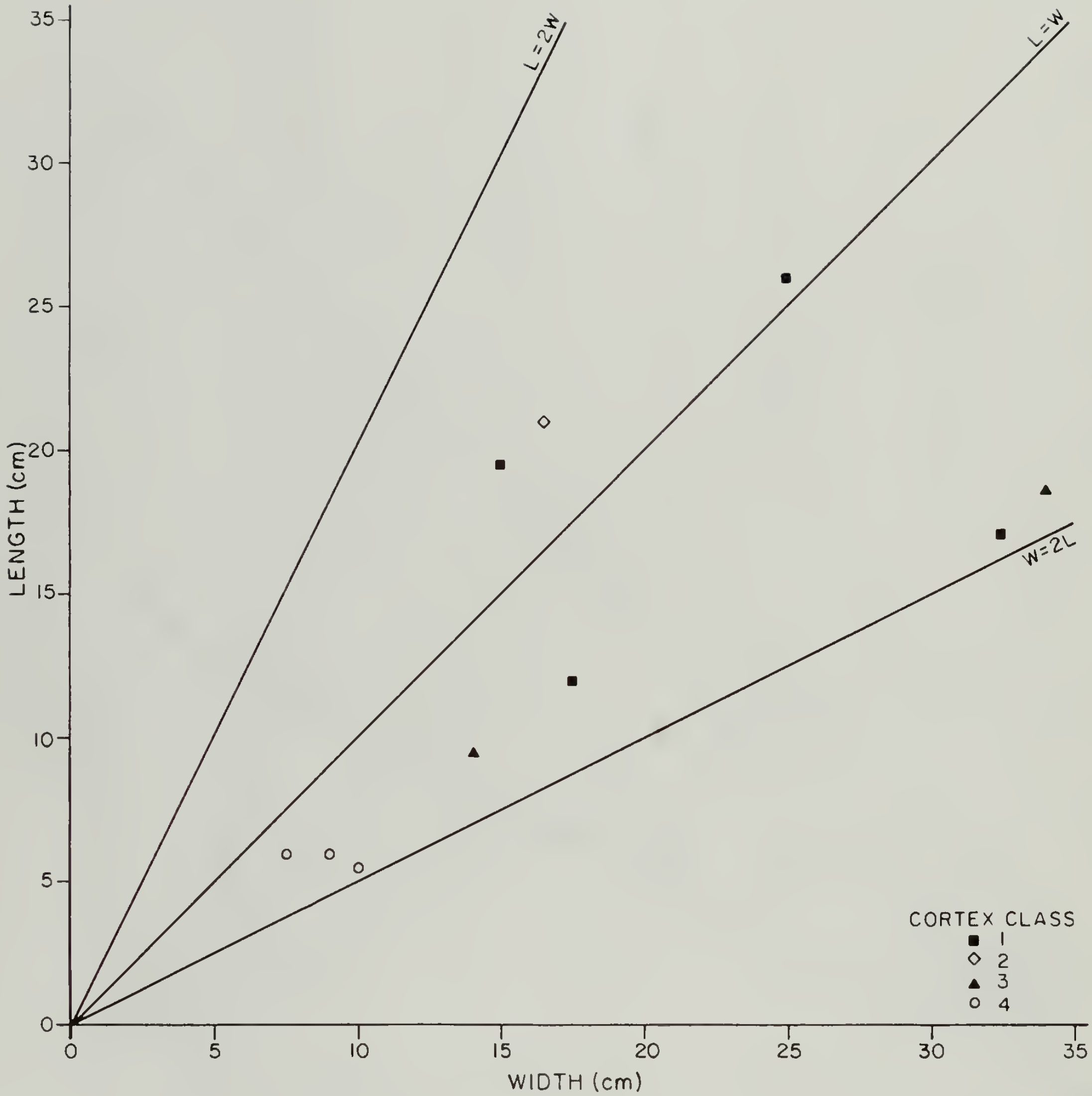

Figure 9. Length and width of flakes plotted by cortex class for Locus 6.

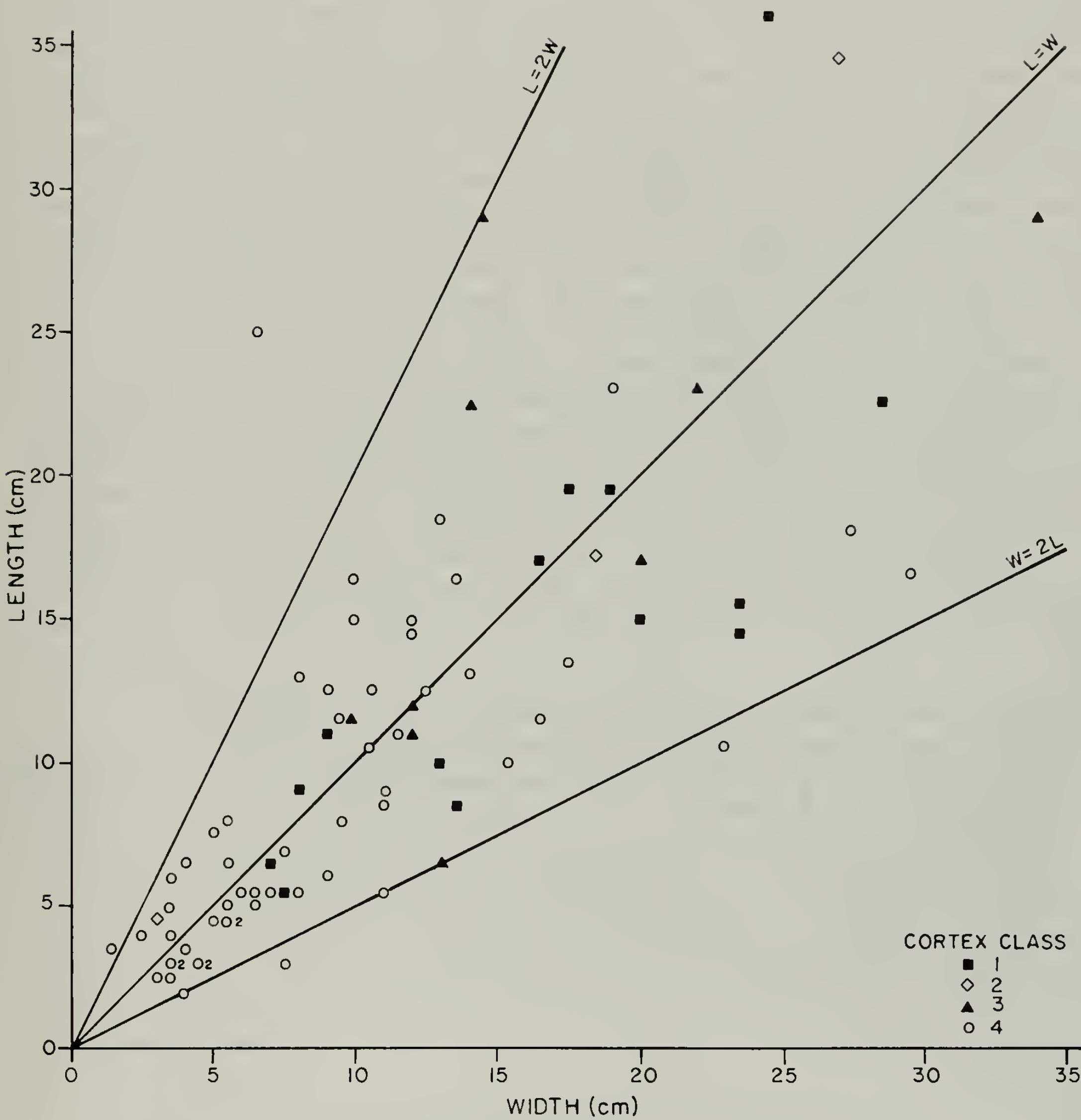

Figure 9. Length and width of flakes plotted by cortex class for Locus 7.

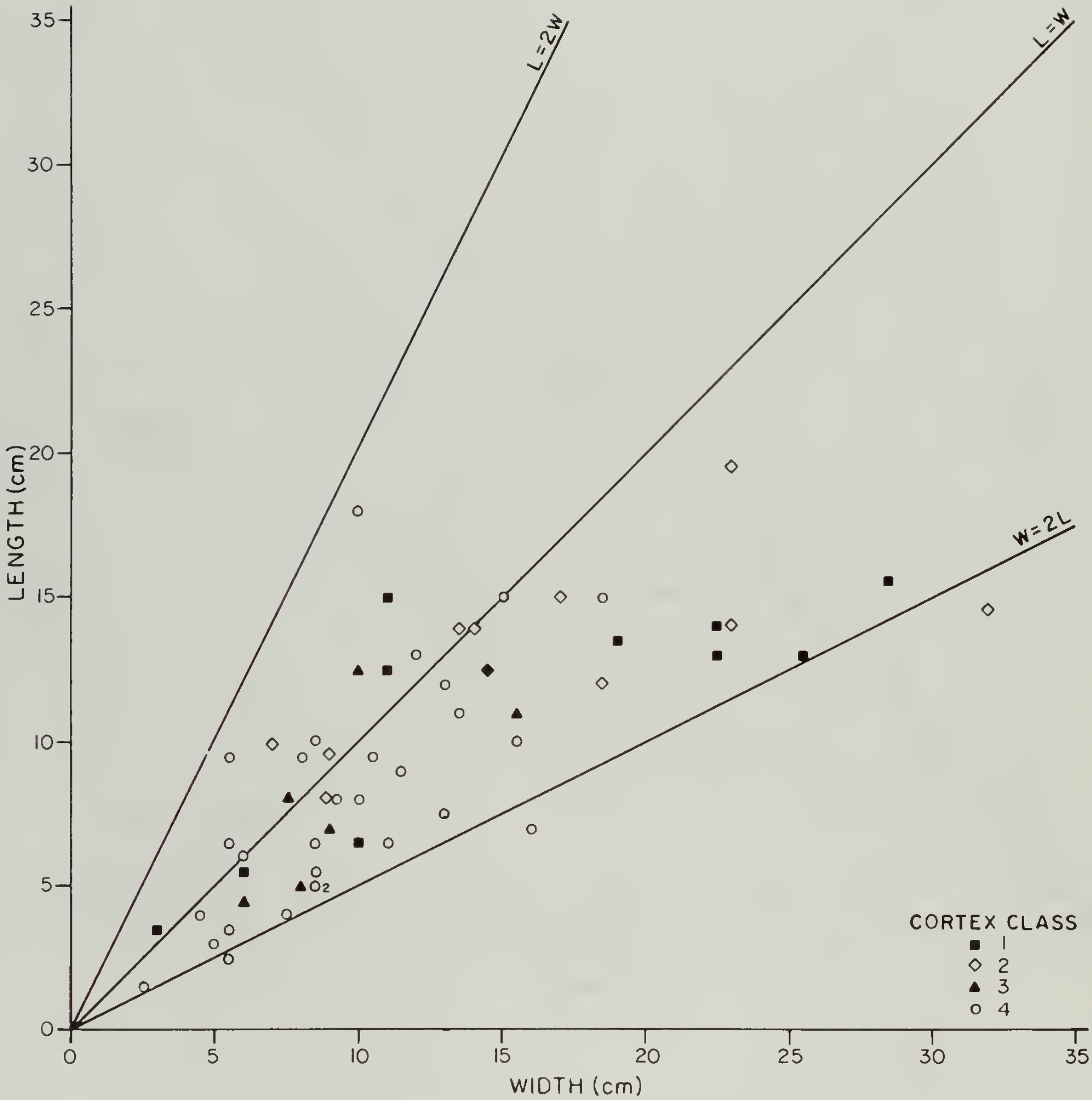

Figure 9. Length and width of flakes plotted by cortex class for Locus 11.

that as expected the smaller flakes are almost all noncortical. With Locus 1, however, the expected pattern is not so clear; the largest flakes are cortical, but there is also a relatively large number of small cortical flakes. In fact, of those flakes less than 10 cm long by 10 cm wide, 45.6 percent have more than 50 percent cortex. At Locus 2 this situation is even more exaggerated; 73.2 percent of all flakes less than 10 cm long by 10 cm wide have more than 50 percent cortex. Further, the largest flakes (those in excess of 15 cm in either length, width, or both) are predominantly (52.3%) those with less than 50 percent cortex. Thus, the Locus 2 debitage provides a suggestion that the typical reduction strategy was not used to flake this particular boulder. It would seem that a series of small cortical flakes was removed initially, or at least early in the reduction process, and that larger, noncortical flakes were removed following this. The presence of a few large, cortical flakes does show that at least in part the typical strategy was used, though to what extent cannot be ascertained. It is possible that configurational peculiarities of the boulder, errors in initial reduction, or some other situational variables dictated that reduction proceed along different lines than normal. The Locus 1 debitage may also tell a similar story. In any case, the Locus 2 debitage apparently reflects the flexibility of the artisans in the manufacturing process. Further, it is clear that future study of production loci using complete flake length, width, and cortex attributes would be productive, and that such data can provide at least some indication of the manner in which the reduction of a particular boulder was accomplished.

The analysis of the production loci has served to document the general nature of the kinds of ground stone implements being produced at the quarry, something of the means by which the work was done, and the kinds of artifacts that usually occur at these loci. When coupled with survey data, what emerges is a picture of an areally extensive quarry, principally geared toward the manufacture of metates from large boulders of andesite in a secondary depositional context (a bajada), by means of percussion flaking. Let us now turn to a consideration of the cultural identity of the artisans, and when they may have been actively using this quarry.

Cultural and Temporal Affinities

One of the most time consuming and difficult aspects of this project was the attempt to identify the cultural and temporal affiliations of the group or groups of people who had utilized the Big Bend area as a ground stone implement quarry. As is true of most quarry sites, diagnostic finished products were not present in any quantity. Further, an almost total dearth of archaeological investigations of any prehistoric or historic aboriginal habitation sites near the quarry area compounded the difficulties. Also, village locations during historic times and presumably prehistorically as well were on the floodplain and low terraces along the Colorado River. Agricultural development of this

area has probably destroyed or obscured the habitation sites, precluding their study at present. Development of these fields did produce finished ground stone tools, some of which were shown me by the McShans and Barrackmans of Needles. However, because of this lack of investigation and the recent disturbance, it is not possible to make a direct link between the quarry site and the nearby former village locations.

While a reasonable amount of ethnological work has been done in the area, the ethnographic literature was frustratingly silent on the subject of ground stone tool production with the lone exception of Stewart's (1968) account. Photographs and a few scattered statements also provided some valuable information. Ultimately, it was this literature and a smattering of archaeological data that permitted at least a tentative identification of the people who used the quarry and a rough approximation of the length of time they had exploited it.

The location of the quarry area at the northern end of the Mohave Valley places it within the territory occupied historically by the Mohave Indians (Kroeber 1902, 1925, 1948, 1951, 1972; Stewart 1983). Kroeber has noted that "The Mohave metate for corn, wheat, and beans is a rectangular block of lava on which a cylindrical muller is rubbed back and forth" (Kroeber 1925: 736). However, he questioned the age of this particular form of metate:

> A myth describes the metate first used by Turtle woman, in Mastamho's presence, as `rounded, not square like the metate of today.' The narrator may have been merely thinking of a ruder implement, as would befit the time of beginnings; or it is conceivable that the native Mohave metate was of the oval Californian type, which went out of use after steel axes allowed the readier shaping of stone (Kroeber 1925: 736).

The reference here to metal axes is presumably to single bitted axes, the poll end of which could be used as a hammer. Such implements have found favor with aboriginal stone workers in widely scattered parts of the world, including Australia (see Binford and O'Connell 1984, Figs. 6 and 7). However, Stewart's information and the experimental work done in conjunction with this project indicate that there is no great difficulty in producing shaped, rectangular metates by flaking "lava" boulders with hammerstones, so metal tools are not a necessary prerequisite for the adoption of this metate form.

Stone pestles were also employed by the Mohave (Kroeber 1925: 736). These were used in wooden mortars, and examples of such implements may be seen in Smith's (1966) treatment of the Mohave. In two pictures (see Smith 1966, photographs facing page 8) the pestles appear to be of volcanic rock, and Bourke (1889: 177) described a Mohave pestle as "a huge affair of lava, eighteen inches long."

Therefore, on general typological and material grounds, it certainly seems that the kinds of food milling equipment used by the Mohave could have been produced from the andesite available from the Big Bend Quarry. Further, Kroeber's notation that Mohave metates are

intentionally shaped blocks of lava accords well with the clusters of "macroflakes" scattered across the bajada surface. Stewart´s informants also indicate that the Mohave were manufacturing identical metates at another quarry only 20 km to the south. It thus seems reasonable to ascribe at least some of this quarrying activity to the historic Mohave, and in fact, a rather large percentage of it could be of Mohave origin. As Kroeber (1925: 802) has discussed, this group seems to have inhabited the Mohave Valley for at least 200 years, and possibly for as long as 350 years, if the Onate expedition did in fact pass through the Mohave Valley in 1605. Even if it did not, it certainly encountered the Mohave Indians only a short distance below the valley along the Colorado River. How much longer the Mohave may have lived in Mohave Valley is at present unknown, but most workers have proposed or accepted continuous Yuman or Patayan occupation of the lower Colorado River Valley since approximately A.D. 1000 (Gladwin and Gladwin 1930; Colton 1945; Rogers 1945).

In an attempt to further establish the cultural and temporal affiliations of the artisans quarrying the andesite boulders, samples of potsherds were collected from isolated vessel breaks and a trail shrine near the investigated production loci. Unfortunately, it is not possible to demonstrate a direct associational link between the ceramics and the loci, but the sherds do provide another circumstantial means of assessing who was present on the bajada and a rough measure of when they were there.

Of the three isolated vessel breaks found near Locus 8 and Loci 1, 2, and 3, all are identifiable as Parker Buff jars. This Yuman or Patayan type was named by Malcolm Rogers, and described by Schroeder (1952: 19-20) and Waters (1982: 567). A historic variant (Parker Buff, Fort Mohave Variant) was described by Kroeber and Harner (1955: 18-19) from Kroeber´s ethnographically collected specimens. Parker Buff is easily recognized by the abundant quartz and feldspar temper. Its age is poorly understood, but a range of about A.D. 1000 to after 1900 has been proposed; the latter quarter to third of this range certainly reflects production of the type by the Mohave Indians. The trail shrine, located south of Loci 9 and 10 by approximately 1.3 km, yielded two decorated sherds and five plain ware sherds. Both decorated sherds are classifiable as Parker Red-on-buff, four of the plain sherds are Parker Buff, and the other plain sherd appears to be Cerbat Brown, a type commonly associated with the Walapai. Parker Red-on-buff is identical to Parker Buff except for the addition of a red painted design, and is presumed to have the same cultural and temporal affinities.

In summary, then, ceramics from the bajada surface indicate as much as a 1000 year record of Patayan use of the quarry area, corroborating the inferences derived from the ethnohistoric literature. By extension, the ground stone production loci are inferred to be of Patayan origin, and an argument can be made that all are the products of historic and prehistoric Mohave artisans. Until such time as habitation sites are excavated in this part of Mohave Valley it will not be possible to more accurately place these loci in a cultural and temporal framework.

Experimental Studies

After the basic reduction sequence was inferred from the preforms, a brief but interesting account of Mohave metate manufacture was found in an article by Stewart (1968). A Mohave informant told him:

> There's a man that picks out good rocks out on the mesa [west of Needles]. . . . He knows just what to pick, and breaks it off with hard rock. He shapes the bottom first, and then turns it over and shapes the face. He fixes it out where he finds it. Just kind of roughens it up out there, then fixes it nice at home (Stewart 1968: 32).

Note that this informant describes, in a few words, the essentials of the process of metate manufacture at a quarry not more than 20 km south of the Big Bend Quarry. The informant has encapsulated the basic reduction strategy, the nature of the work, tools, and processing of the preform at the quarry, and where the finishing work was done. He also indicated that this artisan spent "five or six days' work" shaping the preform on the mesa, and about "a month of work" at home finishing it. These figures seem much too long, but the rest of his statement accords well with the observed archaeological evidence.

Perhaps the most fascinating aspect of the transformation of these large boulders into ground stone implements is the flaking process itself. The debitage resulting from this process is impressive by itself; one does not often encounter flakes that may be over 40 cm in length and width, and made of a material not normally thought of as flakable. However, even more impressive is the technological sophistication, mechanical understanding, and practical experience that the artisans who flaked those boulders had to have to ensure success. It was the limited experimentation conducted by the author that served to underscore these facts. Approximately one-half day was spent attempting to establish, through experimentation, the kinds of technical knowledge needed for successful flaking, mechanical properties of the material, suitable methods of reduction, working positions, and so on. While obviously not an exhaustive experiment, it did serve to help establish some of the basic physical and technical apsects of the process of metate manufacture. The following paragraphs present a description of this manufacturing process, organized along the lines of the major steps of reduction.

As noted above, the artisans were extremely consistent in the selection of only a narrow portion of the range of variation present in the andesite rocks available on the bajada surface. For metates an almost microvesicular grade of rock was preferred, although it might vary in color from dark gray to purplish brown. This particular grade of material can be recognized by cortical characteristics, and probably as well by the sound such boulders produce when struck by a hammerstone. The surfaces of this desired material generally mimic the interior texture of the rock, if the surfaces are not obscured by a heavy coating of desert varnish. It was also noted that nonvesicular materials tended

to ring sharply and clearly when struck, while very vesicular rocks rang less clearly. The microvesicular rock was intermediate in terms of the sound it produced, and it is suspected that to a practiced ear the tone could serve as a rough measure of vesicularity. A dull ring was produced by rocks with internal flaws. Naturally, the removal of a test flake would quickly confirm the nature of the material. The kind of material selected for pestle manufacture appears to be essentially similar, although some use of nonvesicular, porphyrytic igneous material was also made.

In addition to selecting the right quality of material, the initial size and shape of the boulder were also found to be critical. It is probable that an "ideal" boulder would be an elongated, subrectangular to subrounded shape perhaps measuring between 0.75 m and 1.25 m in length, 0.40 m to 0.80 m in width, and 0.20 m to 0.50 m in thickness. Further, there would be natural surfaces of suitable configuration to permit their use as striking platforms, or, at least, their modification by flaking into acceptable platform surfaces. For pestles, suitable elongated cobbles with subrectangular cross sections and measuring between approximately 0.50 m and 1.00 m in length by 0.20 m to 0.30 m in width and thickness would seem to be optimal. Again suitable cortical surfaces for striking platforms would be necessary.

For metates, the flaking process itself appears to have been guided by a preferred strategy of reduction that was utilized whenever possible, with some tailoring to fit situational conditions imposed by the configuration of the individual boulder. Figure 10 presents an idealized reconstruction of this strategy. Evidence derived from aborted and broken preforms suggests that the first step was to remove a series of large, laterally overlapping flakes from the intended top (grinding) and bottom (resting) surfaces. It is possible that in many cases the degree to which such flake series successfully produced a relatively even, flat surface dictated which face of the boulder would be used for the grinding surface. If these initial two series were successful, all that remained to do was the final flaking of the sides and ends of the boulder to produce the desired rectangular preform. Any number of alternative reduction scenarios might develop, however, based on the configurational peculiarities of the boulder and the success of the initial flake series, and how the artisans responded to these situations. Figure 10 is presented as a flow diagram to illustrate how the process may have proceeded. As may be seen from the figure, this is essentially a "two strikes and you're out" kind of format; if a particular operation is unsuccessful and attempts to rectify the resulting problem are also unsuccessful, the preform is abandoned. It is also true that breakage can occur at any point in this sequence, although it is not indicated on the flow diagram. Figure 3f presents a preform broken by a badly directed blow to the edge during the flaking of the surfaces of the boulder.

If the initial flaking of the surfaces is unsuccessful from one margin, the opposite margin or either end can be employed as a platform to achieve the desired effect (Fig. 10). If this is unsuccessful, the edges or ends of the boulder can be flaked in a direction or directions

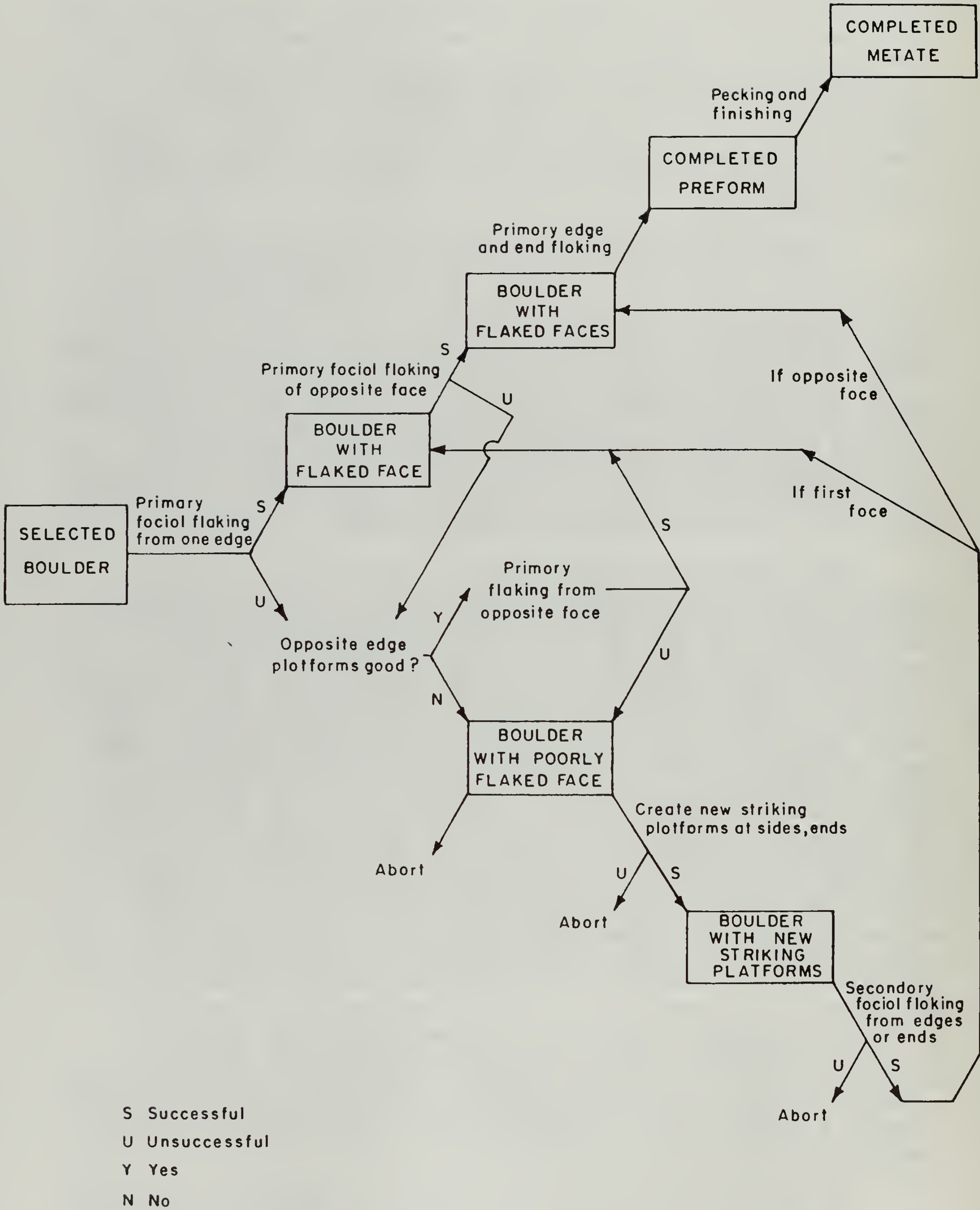

Figure 10. Flow diagram of hypothesized reduction sequence for metate manufacture at the Big Bend Quarry.

perpendicular to the faces. While this aids in shaping the boulder, in this instance its primary purpose is to create a suitable new striking platform surface for the second attempt at flaking the faces (Fig. 10). If the second attempt is successful, final shaping of the sides and ends is done, but if not the preform is usually abandoned at this point. The preform illustrated in Figure 3e was aborted at this stage, after extensive efforts to salvage it using the strategy outlined above proved useless.

The experimentation served to indicate something of the physical parameters governing successful flaking of these andesite boulders. First and perhaps most basic is the question of working position and mode of flake detachment. Preliminary suggestions derived from the BLM survey work were that such techniques as hurling of large hammerstones against the boulder, block-on-block, standard direct percussion, and indirect percussion may have been employed (BLM 1984). My attempts to detach flakes by the overhead hurling of small boulder or large cobble hammers from a standing position were unsuccessful, generally because it was difficult to hit the exact point on the surface being used as the striking platform with the desired portion of the hurled hammer. The detachment of an undesirable flake or the spalling of the hammerstone were common results.

Best results were obtained by direct percussion, using large, unretouched quartzite or igneous cobble hammers weighing approximately 3 kg to 5 kg. The most comfortable, effective working position was found to be that of kneeling in front of the boulder with the striking platform surface facing up and within an arm's length. If the boulder were very large, a standing, spread-legged position was also found useful. Gripping the elongated cobble hammerstone with both hands, the blow was delivered by raising the hammer above the head and bringing it sharply down on the platform surface. Maximum control over the exact point of impact of the hammer on the striking platform surface was obtained using such an approach, and "macroflakes" identical in size and configuration to the largest archaeological specimens were easily produced. Reduction in the force with which the blow was delivered allowed the removal of smaller, 10 cm to 15 cm long flakes. The same end was also achieved with smaller hammerstones one-quarter to one-half the size of the larger ones; these could be manipulated with one hand. It was found that retouched quartzite hammerstones would serve for removing smaller flakes, those 15 cm or less in length.

Indirect percussion flaking was also attempted, but without much success. My wife Lisa aided in this technique by holding a punch (consisting of an elongated, cylindrical quartzite cobble 15 cm in length) on the striking platform surface while I struck it with a large quartzite cobble hammerstone. Even using ideal platform surfaces and angles the technique simply did not yield flakes larger than 5 cm in maximum dimension; it was difficult to deliver a blow with sufficient energy to achieve worthwhile results.

With regard to the physical response characteristics of the material, it was found that optimal flake removal was possible only

within a narrow range of exterior striking platform angles. Although no actual measurements were taken, a range of 80 to 95 degrees was estimated to be optimal. Angles in excess of 95 degrees proved difficult if not impossible to overcome; often a blow on such a platform produced only an incipient cone fracture, the outer (exterior) part of which might produce a short (less than 10 cm) spall that did more harm than good. Angles more acute than 80 degrees yielded flakes, but these tended to be shorter, wider, and have larger platforms than flakes taken from platforms with less acute angles. The large flakes that carried well across a surface and feather terminated all appeared to have exterior platform angles of between 85 and 90 degrees. Given this parameter, and coupled with the great size and mass of the boulders, the positioning of the striking platform surface relative to the stone worker is critical. The surface to be struck must face the worker in such a manner that the blow can be delivered with the greatest amount of force from the most comfortable, stable working position to take the maximum advantage of an optimal platform angle. This is particularly critical for the removal of large flakes. Thus, for at least each separate series of flakes from a different platform surface, the boulder being flaked must be manipulated and positioned for maximum effect. Because it is also important that the boulder be stable when the blow is struck, smaller cobbles may be employed to brace or prop the boulder in the desired position. As noted earlier, this practice was observed at many of the archaeological loci, where abandoned preforms were still propped up on smaller cobbles or where such smaller cobbles were found with obviously fresh scratches on their desert varnished exterior surfaces. Experimental use of cobbles to prop or brace preforms being flaked produced similar scratches on the cobble surfaces in contact with the preform or another cobble. As a final note, it was found that, in their initial form, the boulders being flaked were sufficiently large and heavy so as to require the efforts of at least two persons to position them for flaking. The second person could also aid in steadying the preform being flaked.

The experimental work conducted was simply designed to help answer some rather basic questions, and clearly does not constitute a rigorous exploration of all the facets of this particular technological process. Further experimentation would undoubtedly yield more information, particularly if done under slightly more controlled conditions than were employed for this work. Still, the work accomplished can serve to provide a basis for future experimentation, and is useful in helping to provide a more detailed understanding of the archaeological materials found at the quarry.

Sociocultural Considerations

Another important issue related to the age and affiliation of the quarrying activity concerns the distribution of the ground stone implements being produced at the quarry. Were these implements produced solely for local (that is, within Mohave Valley) use, were they traded

outside the area to other groups, or was there some mixture of these two alternatives? Unfortunately, many of the data needed to confidently evaluate these alternatives are either not available or could not be gathered in the course of this study. What follows is basically a preliminary discussion of these problems, based on extrapolations from available information.

Let us first examine evidence relating to local use of ground stone implements from the quarry. Starting from the ethnographic viewpoint that at least some and perhaps much of the quarrying activity can be ascribed to the Mohave Indians, as argued above, it is instructive to examine demographic data on the numbers of these people, and what their demands for ground stone tools may have been.

For prehistoric and protohistoric horticultural societies, the metate is perhaps, as Haury (1976: 280) noted, "the most important stone tool" because of its daily use for food preparation. There can be little doubt that this was also true for the Mohave. Unfortunately, however, few specific data were collected regarding the technological and socioeconomic aspects of the metate in Mohave society prior to the time when this system was disrupted by Anglo-American contact. The advent of the railroad brought access to processed foods and new tools for grinding such as metal food mills. The metate and other stone milling tools probably fell into disuse by the first or second decade of the twentieth century. Thus, our knowledge of the Mohave metate and its socioeconomic context is quite minimal; the ethnologic information needed to clarify this relationship was never collected, and is now unobtainable. The Mohave metate now belongs largely to the archaeological realm, with some amplification in the form of written words from informants. From these sources it has been possible to reconstruct the technological aspects of the metate, but, unfortunately, little can be gleaned concerning the economic aspects of this tool. However, another line of inquiry may augment the meager Mohave ethnological and archaeological data and thus allow the construction of inferences about this aspect of the economy. This approach involves the use of comparative ethnologic data collected from cultures recently or still producing and utilizing metates. The theoretical justification for the approach is two-fold. First, cultures at similar levels of sociotechnic development facing similar problems may solve them in similar ways, and second, ethnological data provided for contemporary or recent cultures may allow informed consideration of similar aspects of ancient ones. That is, by observing the relationship between material objects and the socioeconomic milieu in a living system one is better able to evaluate the form such relationships might have taken in "extinct" cultural systems.

This discussion can be framed in economic terms, as suggested by Cook (1973). Cook has argued that archaeologists should view the metate not just in terms of a product of a now defunct technology, but "as a human labor embodying product which was produced, exchanged, and utilized by human populations . . ." (Cook 1973: 1485). He assumes a Marxist theoretical perspective, and notes that as material products, metates functioned within a system of production and exchange designed to supply materials for food procurement and processing and to make

the society viable socially. In keeping with this perspective, the following discussion is divided into three sections: production, exchange, and utilization. Each section will largely consist of comparative ethnologic data, coupled with the appropriate archaeological and ethnographic data for the Mohave.

Production

The production of metates includes both the technological process of manufacture and the identity of the workers involved in the process. Insofar as it is presently possible to do, the technological aspects of Mohave metate production have been described. Given the technologically involved manufacturing process, and the requisite technical knowledge and physical skill to carry out the process, it has been argued that this work was performed by specialists. This is in accordance with the implications of Stewart´s (1968: 32) informant´s remarks and information obtained by the author from two other Mohave informants. Therefore, a certain group of skilled individuals within Mohave society was likely responsible for the production of metates, and probably other ground stone tools as well.

How does this arrangement compare with the production patterns seen in other ethnographically known societies? A survey of other Southwestern groups brings to light a very different pattern, one in which the women, the individuals who use the metate, are usually the ones who perform the task of production. For example, let us look first at the Puebloan tribes. Bartlett (1933: 14) and Titiev (1944: 197-198, 1972: 142-143, 243) reported that Hopi women performed the duties of procuring appropriate sandstone slabs and making them into metates. Presumably this work would entail trimming the slabs to fit inside a mealing bin, and preparing the grinding surface by pecking. Hopi women apparently made their own manos as well (Hough 1897). Cushing (1920: 307-308) briefly described the manufacture of the Zuni metate, and related the myth of how Zuni women were shown how to make the item by the "Woman of the White Shells." The process involved regularizing the shape of the stone ("lava") and preparing the grinding surface to be "hollow from end to end, yet flat from side to side." Underhill (1946: 85-86), writing of Pueblo culture in general, described the process of metate manufacture, and noted that "sometimes the men help" by initially chipping the selected stone to shape. However, it was the woman, over a period of weeks, who finished the preform to the desired shape and roughness by pecking. Hill (1982: 80-82) reported that at Santa Clara it was the men who were responsible for the manufacture of metates. He noted that stone and iron tools were used to shape the stone in a "slow and arduous process" into flat-topped blanks 18 inches long, up to 12 inches wide, and 5 to 8 inches thick. This description makes it seem as if the Santa Clara metate was a slightly more technologically sophisticated product than that of the Hopi or Zuni. There is no suggestion, however, that this work was performed by specialists.

Some data on the metate production process is available for non-Puebloan groups as well. Kelly (1964: 37) stated that the Southern

Paiute slab metate was simply ". . . an unsquared slab collected `in the mountains´ and pointed slightly by the woman. . . ." By "pointed" Kelly may mean "pecked," since these slabs are not pointed in shape. Metates formerly used by the Chiricahua Apache were described by Opler (1965: 385) as about 2 feet long by 1 foot wide with ". . . a little depression which the woman makes by pecking it out with another stone and then rubbing it smooth." Gifford (1940: 116) reported that the Tonto and White Mountain Apache used hammerstones to peck the metate to the desired flat-surfaced, ovoid form, though he did not note who did this work. Spier (1928: 114) stated that Havasupai metate manufacture consisted simply of pecking an oval depression for a grinding surface into a slab. While he did not specify who performed the manufacturing, he did describe it as a very lengthy process due to the toughness of the material. The Western Yavapai made no metates according to Gifford (1936: 280), but obtained suitably flat stones, or, occasionally, found serviceable prehistoric specimens. One suspects, however, that some preparation of the grinding surface must nevertheless have been done on these flat stones. Again, however, the identity of the person doing the manufacturing is not specified.

Tarahumara metate manufacture consisted of the selection of a large, smooth, flat rock and the "chipping" of a "groove" (basin?) with a hammerstone (Bennett and Zing 1935: 79-80). According to one source, women performed the manufacturing process themselves (Bennett and Zing 1935: 79), but another source states that the men were responsible for initial shaping of the selected boulder with the blunt end of an axe after which women finished the manufacturing process by pecking (Pastron 1974: 101).

Accounts of Navajo metate manufacture reveal a more complex manufacturing process. Among residents of the east, central, and west reservation, a block of lava or similarly hard rock was selected and chipped and pecked to shape using hammerstones (Kluckhohn and others 1971: 119). Flaking was used to do the initial shaping, and pecking served to smooth and level the grinding surface and edges, and to sharpen the metate. Exactly who was responsible for this work is not specified. In the Ramah area a block of lava of approximately the right size and shape was chosen, its surface pecked with a hammerstone, and ground with another hammerstone to produce the desired grinding surface and shape (oval to subrectangular). Either men or women reportedly performed the work and either could use the metate, although it was generally the women who owned it (Kluckhohn anad others 1971: 117).

It will be noted from the preceding paragraphs that there appear to be some underlying consistent patterns of metate production among the ethnographically known groups in the Southwest. First, it may be observed that the bulk of those groups for which information is available possessed technologically fairly simple metate forms which did not require great investments of time or technical knowledge and skill. Shaping, if done at all, appears to have consisted principally of edge trimming, not full facial flaking as among the Mohave. Preparation of the grinding surface was most often the principal and sometimes only concern, and was accomplished by pecking. Second, it is noteworthy that

metate production seems to have been undertaken principally by women; only at Santa Clara is it specified that men did the work, and, as noted above, the Santa Clara metate may have had a more technologically complex manufacturing effort than many others. This is also true for the Navajo and Tarahumara, and again their metate forms involve either more technical knowledge, or heavier work in preliminary shaping. Production, in the main, seems to have been either largely or entirely in the hands of those who would be using the implement: the women. Thus, among Southwestern groups, the Mohave metate appears to be the most technologically and socially complex in terms of production.

Turning our attention further south into central and southern Mexico, another technologically sophisticated metate is found: the three legged or tripod metate. This particular form was in use as early as the Classic period (A.D. 300) in the Tehuacan Valley and probably elsewhere, and continues to be made up to the present day. A specific description of the manufacture of this type of metate may be found in Cook (1973). Briefly, modern workers begin by quarrying suitably large blocks of igneous rock from bedrock sources, and then work them by flaking or chiseling with steel bars, hammers, and chisels into a basically quadrate form. Material is then removed from one face of the block to produce the characteristic three legs upon which the metate stands, and final adjustments are made to regularize the shape of the entire metate. Finishing consists of the final preparation of the grinding surface with small hand picks. As discussed by Hayden and Nelson (1981) and Nelson (1983), this entire process can also be accomplished with simple stone hammers, as it clearly was prior to the introduction of metal tools. The process is time consuming, with reported rates of manufacture varying from a single metate per day (Aschmann 1949: 685) to three metates being produced over a five or six day work week (Cook 1970: 779). The work is performed by metateros, men with the requisite technical skills and knowledge who devote themselves to metate manufacture on either a full time or part time basis. Such individuals may work alone, with family members, in partnership with others (kinsmen or not), or as employees of others (Cook 1970: 779-780, 1973: 1490-1492). Complex economic arrangements may also develop between quarry owners, the owners of often scarce metal quarrying tools, and the artisans themselves. The social and economic arrangements around which metate production occurs may thus involve a number of persons performing specific portions of the manufacturing process, or all parts of the process may be done by one individual. Regardless of the organizational form which the production process may take, it remains a technologically sophisticated, labor intensive manufacturing sequence performed by persons with specialized skills and knowledge. In this, the Mesoamerican metate manufacturing process may be considered more closely akin to the Mohave metate manufacturing process than the other Southwestern groups discussed above.

Exchange

Following its production, the finished metate is ready to enter into society and begin serving the task for which it was made. The

manner in which this occurs, or the nature of the producer-consumer relationship, is thus the next step of interest in the economic system.

As noted above, in many Southwestern societies the producer and consumer of the metate are one and the same individual; there is no exchange relationship involved. This is the case among the Pauite, Apache, Hopi, Zuni, and probably some other groups. In other societies, including the Tarahumara, Navajo, and at Santa Clara pueblo, men might aid in the production process or perhaps do it entirely themselves. For the most part the relationship of the men to the women is left unspecified in the literature, but one suspects that the husband or another male relative provided the labor. Still, ownership of the finished product was apparently never in doubt, and in most cases the women themselves did the final finishing of the implement. Thus, aside from labor input from a second party, there is no reason to suspect that any exchange relationship was developed.

Within Mohave society some sort of exchange system or relationship must have existed. Stewart's informant, speaking of the one metatero he knew, stated that "He doesn't sell it, but gives to relatives and friends" (Stewart 1968: 32). Some observations are in order here. First, it is clear that an exchange relationship was in existence between the metate producer and his relatives and friends, the consumers. The reference to "giving" the products away is puzzling, but it is perhaps best not to take this statement too literally. It must be remembered that at the time of which the informant was speaking there was only one artisan still active. Thus the whole system of ground stone tool production and use was in decline, and probably nearly extinct. He may therefore not have been entirely familiar with the system by which the product passed from producer to consumer. Further, the informant may have been thinking of "selling" in the sense of the Anglo-American monetary exchange system, a system not in existence prior to contact. In this same line of reasoning, "giving" something away is still an act of exchange, a transaction, and in primitive or nonmonetary economic systems giving generally involves reciprocity of some sort. Such reciprocal arrangements may have been quite simple, or may have involved some societally standardized concepts of appropriate prices for metates and other ground stone products. Thus while we have no direct evidence of the exact nature of the exchange system which existed among the Mohave, it is inferred that one did exist prior to the latter third or quarter of the nineteenth century when ground stone tools ceased to be a vital part of food processing technology. In support of this proposition two important factors may be cited: the existence of a perpetual societal demand for ground stone tools (that is, a market), and the use of a technologically sophisticated ground stone tool production process that put the means of production in the hands of a limited number of skilled artisans. These factors provide the foundation for an economic exchange system of some form.

While we cannot directly infer the form that the Mohave exchange system may have taken, it is informative to see how contemporary societies with similarly technologically sophisticated ground stone tools have structured exchange systems for these products. As noted

above, the Mesoamerican tripod metate is such a product, and Cook (1970) has described in detail the exchange process for this tool in Oaxaca. This study is particularly useful, for it deals with a system of local production and consumption rather than transportation to markets distant from production locales. It is thus perhaps more relevant to the Mohave situation than other studies of Mesoamerican metate production and exchange which involve nonlocal markets and transportation (McBryde 1945: 60-61; Aschmann 1949).

Cook notes that usually the producer of the metate is the person who markets it and receives payment for it, although middlemen traders may act as creditors to the producers and thereby establish claims on their output. Quarry ownership and work organizational factors (partnerships and employer-employee relationships in particular) are critical in determining individual ownership rights to products. Exchange from producer to consumer occurs at a formal market, and usually involves a cash transaction today. Cook demonstrated that selling prices and metate production output covary over the course of the year, and that these variations correlated with the agricultural cycle. That is, production of metates was lowest during that part of the year when the need for agricultural labor (planting, tending, and harvesting) was greatest. This is true because the metateros were themselves farmers, not pursuing metate production on a full-time basis. As stated by Cook (1970: 783), "The majority of metateros consider metate making a secondary occupation, second to farming in priority as a source of subsistence and livelihood. Even in terms of occupational self-image they consider themselves peasant-cultivators (campesinos) first and metateros second. . . ." Metate manufacture thus supplements primary subsistence by farming in normal years for agriculture, and provides a strategy that can be resorted to more heavily in years when agricultural yields are poor. At present it affords the metatero a product that can be sold to raise cash, meaning that he can keep the bulk of his agricultural crop for his own use instead of having to sell it to raise cash. The few full-time metateros work to convert their labors into cash, for they must purchase needed goods and services, including food.

This Oaxacan situation provides an analog applicable to the Mohave metate production and exchange system, namely the existence of a class, probably small, of artisans practicing their craft on a part-time basis as a secondary or adjunct mode of subsistence. The Mohave demand for metates will be discussed in detail in the following section, but it is projected to have been quite low, probably not at a level that would necessitate many specialists working at even a part-time level. However, if these artisans also performed metate maintenance (as indicated by Stewart's informant), pestle manufacture and maintenance, and mano manufacture and maintenance, sufficient work could be found to make it a viable secondary economic strategy. Whether sufficient work existed on a year-round basis, or whether the work was seasonal is not known. Stewart's (1968: 32) informant specifically mentions March as a time chosen by the artisan he knew to work at the quarry; winter was avoided because "the rock breaks." This hints that there was a specific "season" to work at the quarry, but work away from the quarry

(maintenance of metates, manufacture and maintenance of smaller tools much as pestles and manos) could probably be done at any time. Again Stewart´s informant mentioned that five or six days´ work at the quarry, followed by a "month of work at home," was needed by the artisan he knew to manufacture a single metate. If these time estimates are accurate reflections of the pace with which work proceeded, even a month´s work at the quarry could produce sufficient preforms for four or five months´ work at home. The home work schedule could be adjusted as needed or dictated by other subsistence activities, demand for products, or personal inclination. Note also that the length of time mentioned by the informant is far longer than manufacturing times for the Mesoamerican metateros. This may imply that the informant was not really that familiar with the length of time the artisan took to perform the task, or it may be an indication that the Mohave artisan in fact was working at his craft on less than a full-time basis.

The mode of exchange by which a ground stone implement passed from producer to consumer in Mohave society is unknown. Foodstuffs--meat, fish, vegetables--constitute the most obvious medium of exchange, and there are data to show that these products did serve such a function in other segments of the economy. Stewart (1947) described the existence of full-time deer hunting specialists among the Mohave, whose sole function was to provide deer meat to people. Consumers obtained deer meat from the hunter by exchanging fish or vegetables to the hunter for it. It is possible that ground stone tools were purchased in the same fashion from the artisan. The notion of "giving" mentioned by Stewart´s informant may also imply the existence of some form of reciprocity rather than outright purchase. Such an arrangement could take the form of either goods or services. Further, whether a consumer requested or ordered the manufacture of an implement , or simply purchased from an existing stock is not known. If the artisan also performed maintenance work on ground stone tools this might involve a slightly different form of transaction. Whether payment for maintenance differed from payment for manufacture is also unknown. In the final analysis, although it is virtually certain that some exchange system must have existed among the Mohave, it is impossible to determine what form it took.

Utilization

Mohave utilization of ground stone tools has been discussed previously, and by other authors (Kroeber 1925; Stewart 1968). However, beyond simple function, the use of ground stone tools is critical in determining the demand or market for these implements. The demand for such implements, particularly metates, would probably be linked directly to three factors: (1) mechanical attrition, or the wearing of metates through time; (2) the establishment of new households; and (3) Mohave funerary customs.

The attrition of metates through time is a continual process, involving the wearing or grinding away of the working surfaces of both

the metate and muller. Because metates are key implements in food processing, they see use on an almost daily basis, and so attrition can be fairly rapid, depending upon the material from which the metate and muller are made. Further, metates and perhaps mullers must be frequently sharpened when their surfaces become too smooth to permit effective grinding. Bartlett (1933: 4) has indicated that among the Hopi, sandstone metates being used on a regular basis must be sharpened approximately every five days. Sharpening is done by pecking, a percussive process. Metates can thus be expected to wear completely out (see Kroeber 1925, Pl. 56 top, for an example of a Mohave metate in this condition) through use and resharpening, or can be broken during resharpening, thus necessitating a new metate. The length of time a metate might remain serviceable, its use life, is uncertain; Pastron (1974: 101) has suggested that granitic metates used by the Tarahumara have use lives of 20 to 30 years. Aschmann (1949: 685) indicates a 20 year use life for "porous lava" metates in Baja California.

The establishment of a new household would also necessitate obtaining a new metate. A new wife would presumably need her own metate, muller, and pestle if she and her husband established their own household independent of either her parents or his. Often the initial postmarital residence would be that of the husband, but whether this would be within the same structure with his parents or in a separate dwelling is not entirely clear. After children were born, however, a separate dwelling would likely be a necessity, and certainly at this time a set of grinding implements would be required.

When a Mohave dies, he is cremated as soon after death as possible with all his possessions (Kroeber 1925; Stewart 1974); if certain possessions cannot be burned they may instead be physically broken so that the deceased will have use of these things in the land of the dead. Here, then, is another source of attrition for metates, for with the death of a woman her metate was broken or burned. The same practice would presumably hold true for pestles and mullers as well. This practice would mean that it would be unlikely that grinding tools were inherited from one generation to the next, again necessitating the manufacture of new ones.

In summary, Mohave society would have generated a continual demand for grinding implements, based on mechanical attrition and cultural practices. It is possible to roughly measure the strength of this demand, using population data and applying a value for the probable use life of ground stone tools. Again, the metate will be focused on in this case, simply because more is known of its rate of use and wear. First, let us assume the existence of a stable population, one neither growing nor declining in terms of absolute numbers nor changing in terms of demographic structure. Stewart (1983: 57) presents figures for the number of Mohaves living in Mohave Valley prior to extensive contact with European and American society. In 1776 Garces estimated the existence of 3000 people here, and in 1872 a figure of 4000 was given. For this exercise the figure of 3000 will be used. This may be calculated to represent approximately 600 nuclear families, if one assumes an average family size of five persons. If allowances are

made for those who do not marry and for cases of polygyny, perhaps 500 separate households would be represented in Mohave Valley at any one time. At a minimum, each household would be expected to contain one metate, although discussions with Mohave informants suggested that it was not unusual for there to be more than one metate in a given household. The use life of a metate made of the andesite from the Big Bend Quarry is unknown; for the sake of this exercise an estimate of 25 years will be assumed. This would mean that over a period of 25 years, every one of the 500 metates in the valley would be replaced. Over this period they would be lost to both simple attrition and destruction upon the death of their owners. Thus, if these figures are used in simple calculations, a minimum of 2000 metates would be expected to be used over the course of a 100-year period, or at an average rate of 20 metates per year.

How does this compare with the production that may be estimated for the Big Bend Quarry? As noted at the beginning of this report, 944 production loci were recorded in a survey that covered an average of 15.1 percent per section of 24 sections out of an estimated 35 sections within the entire quarry. This does not include the isolated concentration of loci in Section 20, T20N R23W, west of the main quarry. If these loci are assumed to accurately represent 15.1 percent of the numbers of loci in those 24 sections, the figure for all 36 sections of the quarry can be calculated to be 9360 loci. That is, if 944 loci represent 15.1 percent of the loci in 24 sections, those sections should contain an absolute total of 6230 loci, or an average of 260 loci per section. If the quarry covers 36 sections, and if the 24 surveyed form a checkerboard pattern across the quarry area, 9360 loci might be expected in that area. Allowing for the 36 percent failure rate in manufacture discussed above, and assuming that one locus represents one metate, a total of 6042 successfully manufactured metates could be expected to have come from the quarry. When compared to the rate of consumption calculated above, the entire output of the quarry could be accounted for by only 240 (239.6) years of local, intra-Mohave Valley use.

There is another complicating factor, however, in that at least one other quarry for ground stone implements lies within the valley, on the bajada slopes of the Sacramento Mountains west of Needles. This quarry was mentioned by Stewart (1968), and has been identified archaeologically by the McShans of Needles (San Bernardino County Museum Association Newsletter 1985) who informed me of its existence. Because this quarry has never received systematic investigation, its size, intensity of use, and the types of products fashioned there are difficult to compare with the Big Bend Quarry. Mac and Maggie McShan estimate the numbers of production loci at the Needles quarry to be in the thousands, suggesting that the two quarries may be fairly comparable in size and use. The material being quarried here is a light gray rhyolite, very distinct in appearance from the Big Bend Quarry andesite. Through the kindness of Dr. Gerald Smith, I had an opportunity to view two broken metate preforms, two broken pestle preforms, the associated debitage from all four, and six hammerstones that had been collected from the Needles quarry. This collection,

housed at the San Bernardino County Museum Association offices in Redlands, California, indicates close similarities between the two quarries. The Needles production loci are apparently identical to those at Big Bend, consisting of discrete clusters of flakes, often with hammerstones of both local material and retouched Colorado River quartzite cobbles, and often with a broken metate or pestle preform. The Barrackmans of Needles showed me finished metates and manos of the Needles source material, and the McShans showed me finished and unfinished pestles of the same material. It is possible, though not demonstrable at this time, that relatively more pestles and fewer metates were being manufactured at the Needles source than at the Big Bend Quarry.

Still, even assuming that the intravalley Mohave demands for metates were met equally with products from both quarries, and that they were of similar size with similar rates of successful manufacture, the entire output of both quarries could be accounted for by intravalley use over 480 years. The documentary evidence clearly places the Mohaves in the Mohave Valley for the last 200 years, and perhaps for the last 350 years, as noted earlier. It is easily possible that they were there longer. The upshot of the argument is that there is no reason to suspect that the manufacture of ground stone tools at the quarry (or quarries) was designed to serve anything but local demand. Cultural and mechanical factors would ensure a constant need for metates within Mohave Valley.

One may ask, however, whether some metates may not have been traded to nearby groups with whom the inhabitants of the valley maintained friendly relations. As mentioned previously, we are handicapped in attempting to evaluate this on an archaeological level due to a lack of work not only within the Mohave Valley but in regions surrounding it as well. Examination of the archaeological literature and even the Arizona State Museum site survey collections thus proved of no use in assessing the possibility of prehistoric trade. Letters to museums in Arizona and California asking whether their collections contained ground stone implements from this large area brought either negative responses or no responses. We did, however, perform a trace element study of flakes from the 10 production loci investigated by the Arizona State Museum in order to at least see how internally consistent and how distinctive the Big Bend source material may be. Three archaeological samples were also examined. One came from a large Sedentary through Classic period Hohokam village in Phoenix, Las Colinas, from a portion of the site that contained abundant Patayan ceramics. The other two were also from archaeological sites, but were chosen as samples likely to have come from other source areas. One of these was from a Sinagua site near Flagstaff, and the other was from a late Mogollon or Western Pueblo site near Showlow. Tables 3 and 4 present the results of X-ray fluorescence and trace element tests. It may be seen that the 10 specimens from the loci form a relatively consistent group that can be used in the future as at least an initial basis for characterizing the composition of the Big Bend Quarry material. These results can also be useful as a standard against which test results from the analysis of finished ground stone implements found

Table 3

CHEMICAL COMPOSITION OF BIG BEND QUARRY ANDESITE
AND SELECTED OTHER SPECIMENS

Sample	SiO_2	Al_2O_3	CaO	MgO	Na_2O	K_2O	Fe_2O_3	MaO	TiO_2	P_2O_5	Cr_2O_3	LOI	Total
BM-1	56.1	17.1	6.20	3.00	4.31	2.95	7.01	0.11	1.27	0.73		1.31	100.4
BM-2	55.0	17.8	6.15	2.55	4.18	2.87	7.70	0.11	1.49	0.54		1.23	100.0
BM-3B	56.0	17.5	5.69	3.16	4.30	2.86	7.26	0.11	1.33	0.47		1.16	100.1
BM-3C	54.8	17.7	6.31	3.45	4.37	2.71	7.70	0.11	1.47	0.59		0.70	100.4
BM-4B	57.0	17.5	5.29	3.06	4.38	2.97	7.17	0.11	1.34	0.36		0.62	100.1
BM-5A	57.1	17.4	5.58	2.97	4.37	2.96	7.12	0.11	1.31	0.52		0.77	100.5
BM-5B	56.0	17.2	5.48	3.04	4.36	2.99	6.98	0.11	1.31	0.55		0.85	99.3
BM-6	55.0	17.6	6.07	2.92	4.14	2.81	7.62	0.11	1.48	0.61		1.31	100.0
BM-9	56.6	17.5	5.59	3.09	4.37	2.88	7.26	0.11	1.35	0.55		0.70	100.3
BM-10A	56.6	17.8	5.80	2.72	4.33	3.01	6.80	0.10	1.35	0.58		0.85	100.2
BM-ME	51.0	17.2	9.90	5.69	3.39	0.72	10.20	0.14	1.10	0.26		0.62	100.4
FLAG	48.4	15.8	10.10	7.71	2.98	0.77	11.60	0.17	1.70	0.62	0.04	0.31	100.4
NEWR	57.2	16.3	6.85	3.71	4.01	2.60	6.59	0.10	0.97	0.45	0.01	0.54	99.6
SHOL	48.7	15.5	9.61	7.76	2.95	0.78	12.50	0.17	1.74	0.24	0.05	-0.23	99.9

Values are percent by weight.
specimens BM-1 through BM-10a are from investigated quarry loci; FLAG, SHOL, BM-ME indicate specimens from archaeological sites in the Flagstaff, Showlow, and Phoenix (Las Colinas) areas, while NEWR is a sample from the New River quarry sites.

Table 4

TRACE ELEMENTS PRESENT IN BIG BEND QUARRY ANDESITE
AND SELECTED OTHER SPECIMENS

Sample	Cr	Rb	Sr	Y	Zr	Nb	Ba
BM-1	20	70	730	20	320	30	1,510
BM-2	10	60	790	30	370	60	1,840
BM-3B	20	70	750	10	340	40	1,430
BM-3C	20	60	840	20	340	50	2,740
BM-4B	20	70	710	20	360	40	1,290
BM-5A	10	60	720	30	350	40	1,280
BM-5B	10	50	780	10	350	30	2,810
BM-6	10	80	820	30	390	50	1,750
BM-9	20	60	710	30	340	50	1,280
BM-10A	20	70	740	20	360	30	1,230
BM-ME	160	10	500	20	100	20	390
FLAG		20	860	10	140	50	780
NEWR		60	1,020	10	200	30	1,010
SHOL		30	320	30	120	30	310

Values are in parts per million.
Specimens BM-1 through BM-10a are from investigated quarry loci.
FLAG, SHOL, and BM-ME indicate specimens from archaeological sites in the Flagstaff, Showlow, and Phoenix (Las Colinas) areas, while NEWR is a sample from the New River quarry sites.

in the Mohave Valley or elsewhere can be compared, to determine if they might have been manufactured at Big Bend. The samples from the New River andesite source (Hoffman and others 1983) compare fairly closely with the Big Bend material, but significant differences are notable in trace elements such as zircon, strontium, and barium. Metate fragments from Las Colinas, Showlow, and Flagstaff sites clearly are not of the Big Bend material; all are in fact basalt, and though macroscopically very similar in color and texture to the Big Bend material, they are compositionally distinct.

The trade hypothesis draws virtually no support from the ethnographic record. If one first examines the Yuman tribes occupying the Colorado River Valley below the Mohave, one finds that the Quechan (Yuma), Cocopa, and Kamia also employed shaped rectangular metates similar in form to those of the Mohave. However, there is sufficient evidence to suggest that these groups produced their own metates and other ground stone implements from quarry areas within their own territories. The Quechan are reported to have used "in recent times" a source area located near Wellton on the Gila River (Forde 1931: 102), and I was informed by Charles Lamb, Director of the Colorado River Indian Tribes Museum, that ground stone quarrying activity ("macroflake" sites) were known in the area around Parker. Boma Johnson informs me that there are also two quarries near Palo Verde Point south of Blythe, California, where primarily pestles were manufactured. E. W. Gifford (1933: 270) noted that the Cocopa also utilized a source near Wellton for metates; one wonders if this is not the same source as that identified by Forde. Gifford added that the Cocopa had earlier used a quarry in the Cocopah Mountains, a range located 55 miles west-southwest of Yuma and from 20 to 45 miles west of the Colorado River. Historically the Mohave and Quechan were allied against the Cocopa, further lessening the likelihood of trade. Finally, Gifford (1931) also worked among the Kamia. He examined a metate and muller that had been manufactured by and was still being used by a Kamia Indian, who said that the material was obtained from "a mountain in Arizona" (Gifford 1931: 41-42). In view of the position of the Kamia in the Imperial Valley and along the lower reaches of the Colorado River, one wonders if this might not also be the Wellton source noted above. Another Kamia was observed by Gifford using a metate and muller (also of his own manufacture) made of granitic(?) material from a quarry near Jacumba on the U.S.-Mexico border approximately 95 miles west of Yuma. Pestles were also reported to have been manufactured of material obtained at this source.

It thus seems probable that the Colorado River Yuman tribes made extensive use of local quarries for the manufacture of ground stone metates, mullers, and pestles. Raw material suitable for the manufacture of ground stone implements appears to be sufficiently abundant and widespread along the river that there would be little need for trade of this commodity to develop. Likewise, these same facts would tend to mitigate against expeditions by these other river Yumans to Mohave Valley to obtain material directly from the Needles or Big Bend quarries themselves.

What of the possibility of trade of ground stone implements to surrounding, nonriverine tribes? While the Mohave were known as great travellers (Kroeber 1925), they seem not to have done a great deal of trading; Davis (1963: 33-34) has summarized what is known of Mohave trade contacts and the articles traded, and ground stone implements are not mentioned. Further, if one examines the kinds of metates being utilized by these nonriverine groups, it does not seem that the flaked, rectangular Yuman type of metate was in use. East of the Colorado River in Arizona, the Mohave shared borders or contact with the Havasupai, Walapai, and Western Yavapai. The Havasupai are reported to have used a slab or basin metate (Spier 1928: 114), the Walapai employed slab metates (Kniffen and others 1935: 50), and the Western Yavapai utilized either "flat stones" or metates taken from archaeological sites (Gifford 1936: 280). To the west of the Colorado River the Mohave were bordered by the Cahuilla and Chemehuevi (probably a Southern Paiute band), and by other Southern Paiute bands on the north and northwest. Kroeber (1908: 51) reported the use of slab metates by the Cahuilla, and Kelly (1964: 37) indicated that the slab metate prevailed among the Southern Paiute as well. The Chemehuevi, with whom the Mohaves had relatively frequent and, until 1859, friendly contact apparently also used the slab metate. They were even allowed by the Mohave to occupy what is today Chemehuevi Valley; whether they changed to a Yuman type metate as a result of this change in habitat and involvement in agriculture is unknown. It thus appears that insofar as metates are concerned, the Colorado groups and surrounding desert groups had separate forms, and there is no evidence of trade of metates during the ethnohistoric period.

It is still conceivable that some minor trading of ground stone tools may have occurred in prehistoric times or historic times, though the data needed to evaluate this possibility remain to be gathered. Still, the difficulties of pedestrian transportation of objects as heavy as a metate (or even a pestle) make it seem unlikely that overland trade of such objects was ever carried out on a large scale. Another factor making trade less likely is that even if andesite, basalt, or other igneous rocks were viewed as optimal materials with which to make ground stone tools, the Big Bend source is but one of dozens of potential sources present in western Arizona. Examination of a geologic map (Cooley 1967) reveals just how common and widely distributed such material is from Flagstaff and Phoenix west to the Colorado River. In short, access to these materials is widespread all across the western half of the state. Further, there are other known ground stone implement quarries west of the Colorado River. These include a quarry near Daggett, California, where metates and pestles were manufactured from a porphyrytic igneous rock (San Bernardino County Museum Association Newsletter 1985), and another quarry in the Picacho Basin of California where pestles and stone bowls were being manufactured (Pendleton 1984).

In summary, it is suggested that all, or virtually all, of the quarrying activity known at present to exist at the Big Bend Quarry can be logically accounted for by intra-Mohave Valley consumption over a relatively short period of time. There is no need to posit the existence of a sophisticated network of metate production and trade involving non-Mohave groups, at least based on the evidence at hand.

Summary and Conclusions

The BLM survey work and limited data recovery operations by the Arizona State Museum have served to bring to light a fascinating ground stone tool quarrying site along the lower Colorado River in the Arizona-California-Nevada tristate area. Using archaeological and ethnological sources, it has been possible to demonstrate that the quarrying activity is of Mohave or ancestral Mohave (Patayan) origin, and may represent only a few hundred years of intensive use. Study of the quarry at Big Bend has indicated that metates were the principal products being manufactured from large boulders of andesite, although some pestles (and possibly mullers and mortars as well) manufacture was also undertaken. From detailed examination of broken or aborted preforms and debitage from their reduction, it has been possible to reconstruct an idealized manufacture or reduction sequence for metates. This entails the percussion removal of large cortical flakes from the intended grinding and resting surfaces, followed by flaking of the sides and ends of the preform. Pecking is used for the final finishing and shaping of the entire preform. Limited experimentation has provided a rudimentary understanding of the high level of skill, technical knowledge, and experience necessary for the production of metates using this method.

Through the use of Mohave ethnologic data, supplemented by comparative data from other Southwestern, Great Basin, Californian, and Mesoamerican societies, it has also been possible to attempt to reconstruct the social system within which the production, exchange, and utilization of metates occurred. Production of ground stone implements by part-time or possibly full-time specialists, serves to distinguish the Mohave and perhaps their Yuman-speaking riverine kinsmen from surrounding cultural groups. Although the nature of the exchange relationship which fostered transfer of ground stone tools from producer to consumer is uncertain, it was probably based on the use of goods or services as a medium. Again this distinguishes the Mohave from their non-Yuman neighbors, where usually the producer and consumer were one and the same person. The most similar surviving example of how the Mohave system may have functioned is found in Oaxaca, where peasant-artisans produce metates as a supplement to their primary occupation as farmers. Finally, the mechanical and social factors governing use of ground stone tools were examined, and used to generate parameters of the demand for these products. Using the results of calculations based on these parameters, it was possible to demonstrate that intra-Mohave Valley use of the products from this quarry could account for its entire projected output in a few hundred years.

The presence of such a technologically sophisticated system of ground stone tool manufacture has been shown to have implications for societal organization in terms of production and exchange. The concentration of the means of production in the hands of a few specialists creates the need for some form of economic exchange relationship by which the products are passed from the artisan to the consumer. The form which such relationships may take is illustrated in the Mesoamerican case study by Cook (1970, 1973). Clearly, the presence

of a technologically sophisticated material product, even in so-called "primitive" or "nonmarket" economic systems, can have major effects in economic and social organization and integration. For example, the well made, carefully shaped trough metates of volcanic rock present in Hohokam sites may be taken as a sign that some sort of economic subsystem similar to the Mohave and Mesoamerican cases probably existed in central Arizona prehistorically. The New River ground stone implement quarries documented by Hoffman, Doyel, and Elson (1980) further demonstrate the likelihood that such a system existed among the Hohokam. It is not unlikely that other such quarries exist in central Arizona. Further, other prehistoric societies may also be found to have had such systems of ground stone tool production and exchange.

Further work at the Big Bend Quarry could be productive. More specific data on the reduction strategy or strategies employed would be useful, as would detailed study of pestle, muller, and mortar manufacture. Specifically, intensive examination of the isolated high density quarry area west of the main quarry could be enlightening to help document the range of quarry products and explore the possible differential use of specific areas within the quarry area for specific products. Also, further experimental work could aid in assessing details of the reduction process for metates and other tools. In addition, survey and detailed study of the recently discovered quarry west of Needles is needed. The same would be appropriate for the other quarries known either archaeologically or ethnologically along the Colorado River downstream of Mohave Valley. Comparison of variability in types of products, cultural and temporal affiliations, and reduction methods among these quarries would be very useful for further consideration of how these critically important ground stone tools were produced, exchanged, and used.

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